Contents

Cover   *A NIKE ZEUS anti-missile missile is test-fired at White Sands Missile Range, N. M. The ZEUS Acquisition Radar receiving antenna is in the foreground. (See story on page 78)*

VANDENBER[G]

WSMR

PT. MUGU

C. A. Warren

KWAJALEIN ISLAND
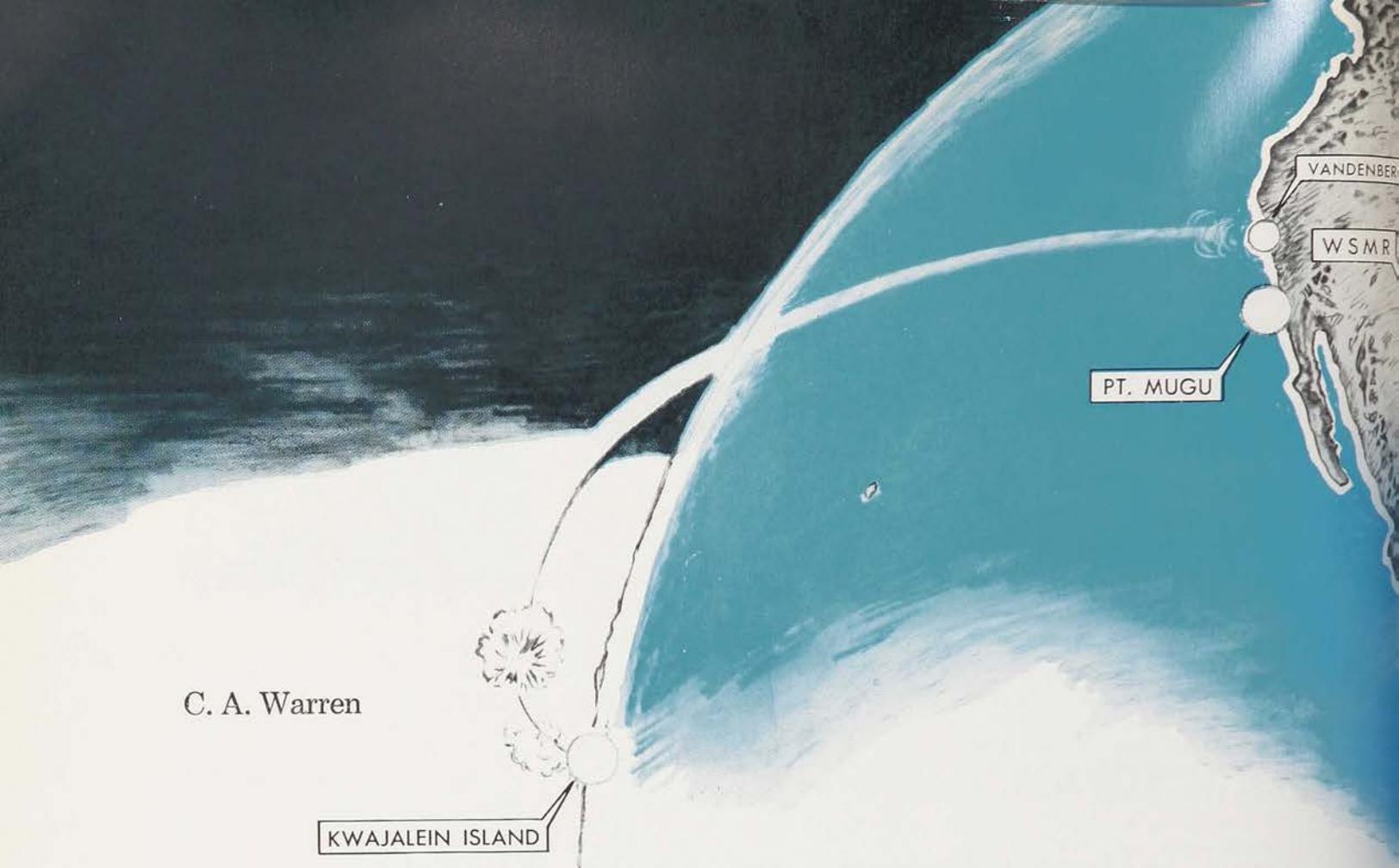
NIKE ZEUS

IN 1945 BELL LABORATORIES was asked by the military to look ten years into the future, and design an anti-aircraft system for defense against highly-maneuverable supersonic bombers flying at altitudes outside the range of anti-aircraft guns.

The problem seemed almost insurmountable.

A system study was initiated, however, and the resulting weapon systems—NIKE AJAX, followed by NIKE HERCULES—not only met the original threat parameters but extended target capability during development to several times the altitude and speed range of any manned bomber known to be operational in the world even today.

In February, 1955, Army Ordnance asked the Laboratories to look again into the future. This time the aim was to find a defense against ballistic missiles, which were expected to be operational between 1960 and 1970. Particular emphasis was to be given the Intercontinental Ballistic Missile (ICBM). The situation was unlike that in 1945—then the target was one which had been under development for many decades. In 1955, an ICBM had yet to be flight tested.

The concept of the ICBM opened up a new era of offensive capability; threat parameters were several orders of magnitude above that of the most advanced manned bomber. Again the problem seemed almost unsurmountable, but the Laboratories agreed to conduct an 18-month study to investigate the possibilities of designing a defense against what was commonly referred to as "the ultimate weapon."

The results of the study were presented in the Fall of 1956 to the Army Chief of Research and Development as well as to members of the Department of Defense; early in 1957, authorization was received by Western Electric for Bell Laboratories to develop a ballistic missile defense system for the continental United States. This system was later named NIKE ZEUS, and its development was given the highest priority.

To understand the problem involved in this development program, the scope of the new threat must be understood. The rapid development of long range ballistic missiles revolutionized the whole scope of the air threat. Ballistic missiles
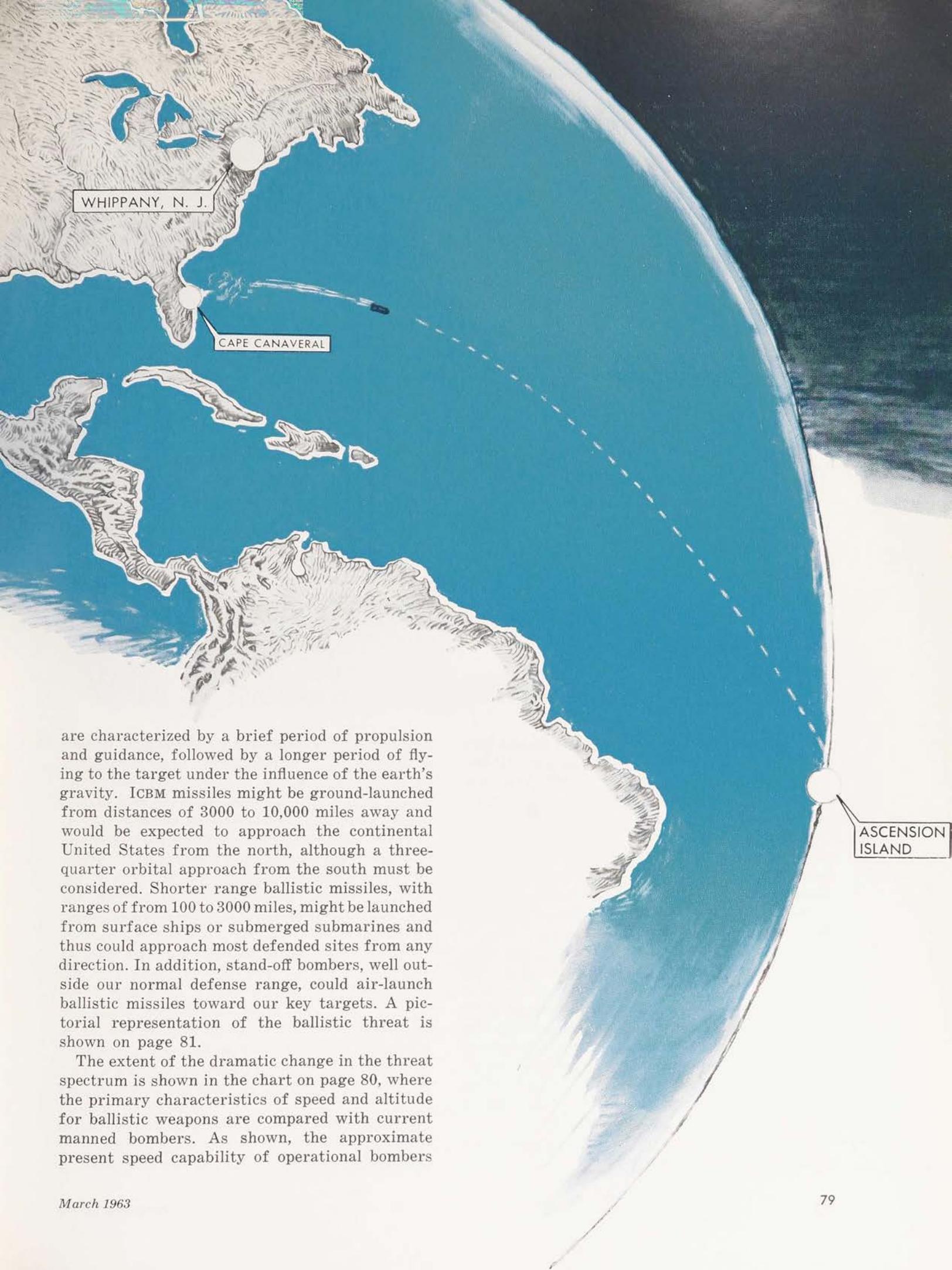
WHIPPANY, N. J.

CAPE CANAVERAL

ASCENSION ISLAND

are characterized by a brief period of propulsion and guidance, followed by a longer period of flying to the target under the influence of the earth's gravity. ICBM missiles might be ground-launched from distances of 3000 to 10,000 miles away and would be expected to approach the continental United States from the north, although a three-quarter orbital approach from the south must be considered. Shorter range ballistic missiles, with ranges of from 100 to 3000 miles, might be launched from surface ships or submerged submarines and thus could approach most defended sites from any direction. In addition, stand-off bombers, well outside our normal defense range, could air-launch ballistic missiles toward our key targets. A pictorial representation of the ballistic threat is shown on page 81.

The extent of the dramatic change in the threat spectrum is shown in the chart on page 80, where the primary characteristics of speed and altitude for ballistic weapons are compared with current manned bombers. As shown, the approximate present speed capability of operational bombers
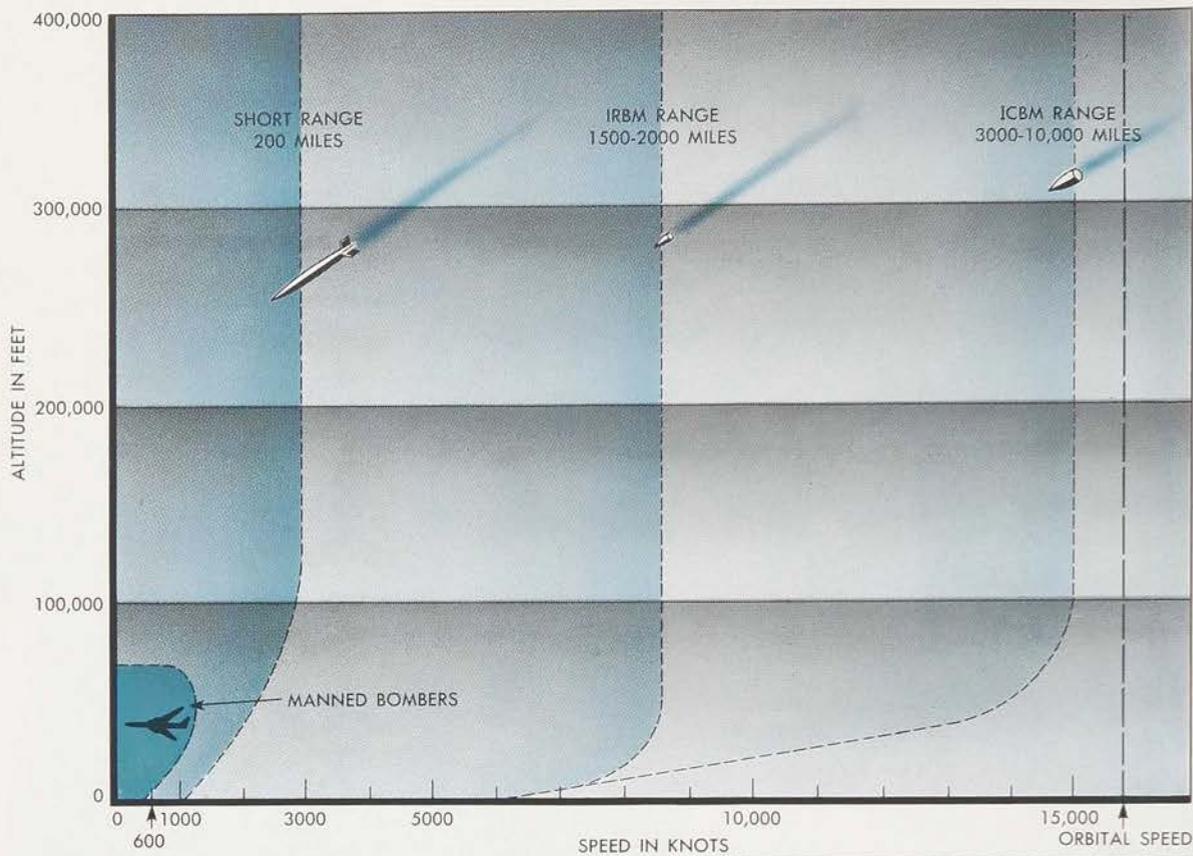
Primary characteristics of speed and altitude for ballistic weapons, compared with conventional manned bombers.

is up to 1000 knots and altitudes up to 80,000 feet. Well outside the bomber range lie the ballistic missiles, whose speeds vary from 3000 knots for shorter range ballistic missiles to about 15,000 knots for the ICBM, and whose trajectories extend hundreds of miles above the earth. Arrival angles in elevation for ballistic targets can vary from about 15 degrees to 70 degrees, with little correlation between the re-entry angle and speed.

The defense problem, made difficult by the extreme speed of an ICBM, is compounded by the small cross-section of the re-entry body carrying the warhead. In some cases, this cross-section could be less than one-thousandth the cross-section of typical manned bombers. Both of these characteristics combine to reduce drastically the time available between detection and interception of the ICBM warhead. Also, because there are no appendages or guidance elements to attack physically, the objective of the defense must be to disable the nuclear warhead itself.

Like every air threat of the past, various forms of countermeasures can be expected by the de-

fense as part of a ballistic missile attack. In particular, an enemy would attempt to develop decoys to accompany the warhead re-entry body that would be indistinguishable from the real target, hoping to "confuse" the waiting defense.

Taken together, the speed, radar size, approach characteristics and countermeasure possibilities of the ballistic class of targets, particularly the ICBM, combine to make the defense problem far more difficult than defense against the current manned bomber.

Certain ICBM characteristics aid the defense, however, in comparison with bombers. For example, outside the atmosphere, ICBM nose cones follow highly predictable trajectories which are fixed only by the laws of physics. Hence, early information can be used to determine the warhead's entire course to impact. Also, there is no low altitude approach threat even at the lowest re-entry angles.

Conceptually, there are three different stages at which a system for intercepting ballistic missiles could be effective: During the early portion

Ballistic missile threat could come from almost any quadrant, depending on whether the missiles were intercontinental, intermediate or short range.

of their trajectory, just after launch; during their mid-course flight; or during the terminal phase as the ballistic missile re-enters the atmosphere headed towards its ground target. The NIKE ZEUS system is being developed as a terminal defense anti-missile system; consequently the weapon elements of the system would be located in the general region of the specific areas to be defended.

Some understanding of the fundamentals of such a defense system can be gained from analogy with an outfielder in a baseball game. As soon as possible after the crack of the bat (launch of the ball on a ballistic trajectory) the outfielder must detect the ball in flight and make a coarse prediction of its trajectory to see whether it will come within his range of coverage. An outfielder's field of coverage depends on how soon he predicts the path of the ball and starts to run in the approximate direction as well as on how fast he runs. During the flight he keeps looking over his shoulder to re-check the position of the ball, correcting his speed and direction as the intercept approaches. Finally, when in position, he performs the fine

guidance and terminal steering maneuver by moving his gloved hand to catch the ball. In this analogy, it is important to note that the outfielder moves at a much slower rate than the ball he is trying to catch; the ratio of speeds is not much different than those of NIKE ZEUS and its target.

For defense against ballistic missiles, the NIKE ZEUS system (similar to its predecessors HERCULES and AJAX) would employ radar tracking data and command guidance throughout the engagement to direct a high performance aerodynamic and reaction-controlled missile to intercept the ballistic target with sufficient accuracy to destroy its warhead.

The ZEUS system is designed to be divided into two major areas as shown on page 82. These are:

(1) The ZEUS Defense Center, consisting of the ZEUS Acquisition Radar and the associated data processing equipment.
(2) The Weapon Batteries, including the tracking radars, guidance computers, and ZEUS defensive missiles.

Detection of ballistic targets coming from any
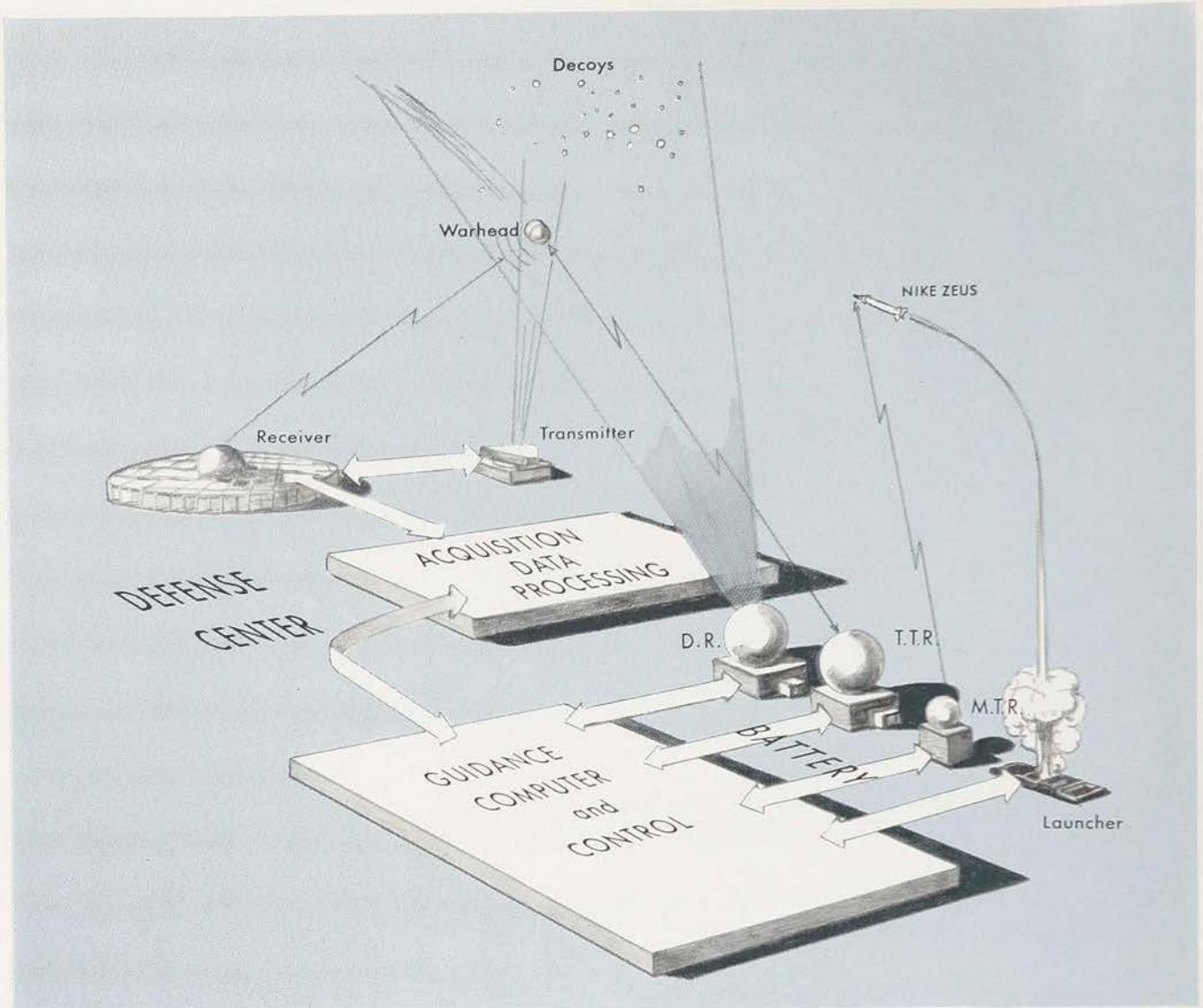
Defense system is divided into two areas: Defense Center with its acquisition radar and data process-ing equipment, and Weapons Battery, with track-ing radars, guidance computers and ZEUS missiles.

azimuth or elevation approach angle is the function of the powerful ZEUS Acquisition Radar at the Defense Center. This radar uses separate transmitting and receiving antennas. The latter is in the form of a hemispheric Luneberg lens. The acquisition radar is capable of scanning millions of cubic miles of space per second in search of very small targets. The data processor would receive the output of the radar and determine from ballistic trajectory predictions what targets come within range of the Defense Center. Those judged threatening to the defended area would be assigned to an associated Weapon Battery for defensive action. Like the baseball outfielder, defensive action cannot be initiated until the approximate flight path has been determined.

A Battery would contain the elements necessary to guide ZEUS defensive missiles to intercept ICBMs speeding in on their elliptical paths at four miles per second: Target and Missile Track Radars for obtaining position data on both targets and defensive missiles, ZEUS missiles in underground cells ready for immediate launching, and computers for generating the steering orders to ZEUS missiles in flight that will bring them within lethal radius of the ICBM targets.

The function of the Discrimination Radars in the Battery is to track a specific grouping or "cloud" of objects that could be spewed forth by an ICBM during its flight to confuse the defense, and to select for intercept those judged by their characteristics to be threatening warhead(s). Prior to actual intercept, highly precise, needle-beam Target Track Radars in the Battery would take over automatically to provide the accurate data on the ICBM warhead positions.

The guidance computer would predict both the path of the ICBM and the proper time to fire the ZEUS missiles. Missile Track Radars are designed to follow each ZEUS missile accurately in flight and transmit steering commands and, at the appropriate time, the special ZEUS warhead would be detonated.

The basic differences between a NIKE ZEUS anti-ICBM defense system and a bomber defense of the HERCULES and AJAX types are essentially quantitative, and are imposed by the very high ICBM speed—25 times that of a typical bomber. Time is therefore precious, and the elements of ZEUS have been designed to gain as much time as possible and to make effective use of every second. ZEUS radars have been increased to much greater ranges than have ever been required for a bomber attack to help compensate for the higher ICBM speeds and to gain time for defensive action. For the time available for defensive action, the range of coverage of the ZEUS Battery is directly related to how fast the ZEUS missile gets up to speed and how fast it can travel. Hence there must be a proper system balance, in terms of feasibility and costs, between radar ranges and defensive missile speed, since every second cut off the flight time to a given range reduces the radar requirement by several miles. Like the baseball outfielder discussed earlier, the same factors of early detection, identification of direction and speed determine the area of defense coverage for NIKE ZEUS.

Taking off like a jack rabbit from its ready vertical launch position under the impulse of about a half milion pounds of booster thrust, the ZEUS missile travels to higher speed and altitude, under more exacting environmental conditions, than any previous defensive missile developed in the Free world. Unique protection techniques are required to shield the missile from the thermal effects of its terrific speed. Through the use of both aerodynamic and reaction thrust control, ZEUS can be under absolute command control within *and* outside the atmosphere.

With time so precious, ZEUS has been designed for fully automatic response, from the initial detection of ballistic missile target(s) by the Acquisition Radar to the actual firing and guiding of ZEUS missiles to interception by the Weapon Battery. High speed data processing equipment specifically designed to meet the levels of reliability essential to an anti-ICBM system perform the many computer functions in times measured in millionths of a second. Thus, although the functions of target sorting, identification, tracking, and guidance calculations are extensive and complex, little time will be lost in carrying out the

fully automatic chain of operations. Redundant communication data links operating with negligible delay connect the various elements of the ZEUS system, so that the data processing equipment functions as if all parts were installed at one location.

ZEUS requirements for substantial improvements in range capability forced radar technology to take a giant step forward in improved over-all performance, after some 20 years of continuous development. Fortunately the development of low-noise solid-state amplifiers, high-level r.f. power sources, improved capabilities in the engineering of large, accurate antenna structures provided the ingredients necessary to achieve these radar advances in the ZEUS system.

The ZEUS system field tests have drawn heavily upon the Laboratories background of experience gained during the 17 years of research and development on the AJAX and HERCULES systems. However, there are three principal differences that make the test of a ballistic missile defense considerably more inconvenient and difficult.

### Problems in Testing Ballistic Missile Defense

First, all the characteristics of a conventional bomber, coming for example from 5000 miles away, can be duplicated by a relatively short range flight at a United States missile test range. In contrast, the target characteristics of an ICBM can only be faithfully duplicated by a full-range flight. Thus ZEUS, designed as a terminal defense system, must be installed for the real intercept tests at remote sites—with all the disadvantages involved for personnel and logistics.

Second, the ZEUS defensive missile must be capable of operating outside the atmosphere. For missile tests above the atmosphere, aerodynamic drag cannot be used to terminate the missile's flight quickly; hence a test range many times the nominal intercept range is required for full development tests of the missile.

Third, there are a large number of target and intercept conditions applicable to an ICBM defense which do not apply to defense against aircraft; hence a more complex test evaluation program is required.

These testing differences have made it necessary to establish three ZEUS test sites in the United States and two sites overseas, as shown on the title page. It is interesting to note that the overseas sites at Kwajalein Island in the Pacific and the one in the Atlantic on Ascension Island are almost exactly on opposite sides of the world, 12,000 miles apart.

One of the United States sites is the Whippany
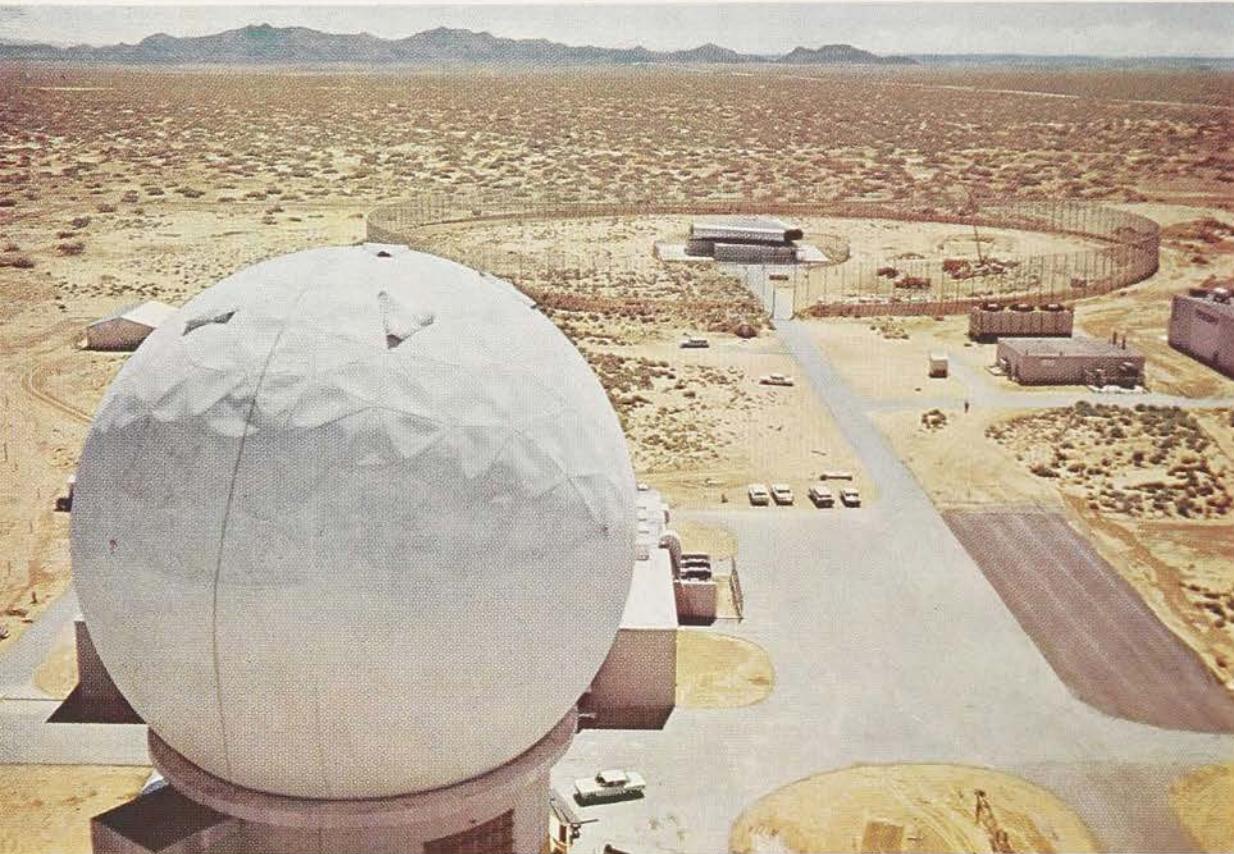
NIKE ZEUS receiving and transmitting antennas at White Sands Missile Range.

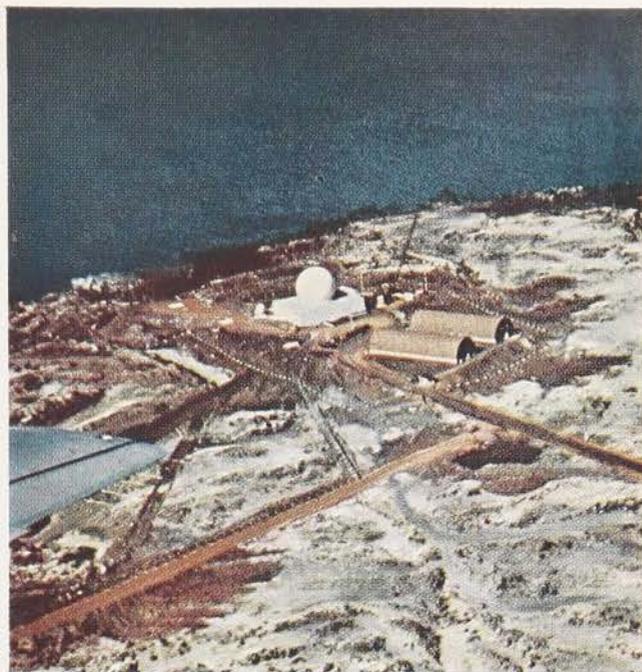*NIKE ZEUS in its launching cell at WSMR.*

Receiving and transmitting antennas at Kwajalein Island.

NIKE ZEUS Battery Control building at Kwajalein.

The elements of a ZEUS defensive system, including four missile launching cells, are installed at Kwajalein Island.

Target Track Radar on Ascension Island gathers data on ICBMs test-fired from Canaveral.

location of Bell Laboratories. Here, all the major elements of the system except the Acquisition and Discrimination Radars and the missile itself are tested initially. The tests at Whippany are a continuing part of the development of the system elements and support the system testing at the remote ZEUS field locations. A partial view of simulation equipment at Whippany is shown on page 86; thousands of electronically-simulated test intercepts against ICBM targets have been made to evaluate the system's capability. Such testing will continue, to correlate field test results with those obtained by simulation.

At Ascension Island, a ZEUS Target Track Radar, similar to one installed at Whippany, has been installed as shown at right, above. A trained operating crew of Bell Laboratories and Western Electric engineers on this lonely volcanic island are concerned with gaining operating experience and important data on ICBMs being fired down the Atlantic Missile Range from Cape Canaveral to impact in the region near Ascension Island. Valuable information on the target characteristics of ICBMs is being measured during the terminal phase of their ballistic flight, and such information is applicable to anti-missile defense.

The White Sands Missile Range (WSMR) is the key ZEUS test site in the continental United States. Here, all elements are brought together for an over-all system test, short, of course, of intercepting ICBM targets. WSMR also provides a highly instrumented overland range for develop-

ing and evaluating the ZEUS missile for operation within the atmosphere and testing the powerful ZEUS radars. The large spherical Luneberg receiving antenna for the ZEUS Acquisition Radar installed at WSMR is shown on page 84. The data processing equipment for the Acquisition Radar is installed in the building adjacent to the receiving antenna. The triangular-shaped acquisition transmitting antenna is shown in the background. The powerful transmitters feeding the antenna are located below ground. The fence serves to reduce ground clutter to a minimum.

The other continental United States ZEUS site was at Pt. Mugu, Calif. It provided the long overwater range which was necessary to test the missile at altitudes outside the atmosphere, until it ceased operation last December. This site was primarily concerned with missile tests and hence only a part of the ground guidance equipment was installed for these operations.

The final and most important ZEUS test site is on Kwajalein Island in the Pacific, where the system is being evaluated against target vehicles launched by ICBM boosters from Vandenberg Air Force Base in California, about 5000 miles away. Here, the weaknesses and strengths of the offense and defense in this new field of ballistic missile weapon technology are being evaluated in a research and development test program.

An air view of the horseshoe-shaped Kwajalein Island is shown above. The 819-acre island is up to one-half of a mile wide and about 2½ miles

Thousands of electronically-simulated test intercepts have been made with this equipment at Whippany.

long. It has a tropical marine climate which is fairly constant most of the year, since it is only about 8 degrees above the equator. Annual rainfall averages 102 inches; both the relative humidity and temperature average a steady 82.

Although not a complete tactical system, elements making up a ZEUS system, including four missile launching cells are being located at the end of the island, and the family housing and other logistic buildings are at the opposite end. The airport runway, as seen, occupies a large portion of the little coral island.

The system installed at Kwajalein is essentially the same as that at WSMR except the large spherical Luneberg lens, shown earlier at WSMR, is replaced by a hemispherical Luneberg lens receiving antenna and a large ground plane as seen at left. The Battery Control Building at Kwajalein, in which the ground guidance equipment is installed is shown below it. Only a minimum number of system elements making up a firing battery have been installed at Kwajalein. In the photograph, two Missile Track Radars are shown installed. An optical tracker range instrument is also visible near the Battery Control Building.

An anti-missile defense system must be able to cope with any feasible combination of target parameters, decoys and intercept conditions. The test program at Kwajalein is intended to gain increased knowledge of the capability of an anti-missile defense by a planned series of test conditions to explore the full range of ballistic missile threat characteristics.

Nike Zeus Team

NIKE ZEUS development has called upon the wide range of talents available not only within Bell Laboratories and Western Electric but also the specialized skills of some 14 major subcontractors and hundreds of other small subcontractors. Within the Laboratories, the Physical Science Research Division, Mathematics Center, Solid State Device and Component areas, Communication departments and Military Research are some of the specialized supporters of the NIKE ZEUS project. Team effort between the Laboratories and Western Electric was required as never before to help build and install, within a very tight time schedule, the large and complex ZEUS antennas and electronic equipment at the remote Atlantic and Pacific Sites. This required not only their wide range of manufacturing skills but also their specialists in equipment engineering, transportation, installation, and field force engineering. The principal subcontractors include Douglas Aircraft Company, Continental Can Company, Goodyear Aircraft Corporation, Remington Rand Univac, Sperry Gyroscope, Steel Products Engineering, Continental Electronics Manufacturing, Burns and Roe, Inc., Dow Chemical Company, Armstrong Cork Company, Texas Instruments, Inc., Lear, Inc., Thiokol Chemical Corporation, Advance Structures, Inc., Cornell Aeronautical Laboratory, Avco-Everett Research Laboratory, and New Mexico State University.

A waveguide network designed at Bell Laboratories makes it possible for one microwave route to carry the three frequency bands in which Bell System common carrier radio systems operate.

A Microwave Systems Combining Network

A. J. Alberts

I N THE LAST FEW YEARS telephone, television, and data communications traffic have increased beyond the capacity of the radio relay systems available to them in many parts of this country. A way to meet the increased demand for service might be to construct a second system parallel to an overloaded one. But this necessitates a complete new investment in towers, buildings and real estate. A more practicable way to an equal result is to stack additional systems on an existing one and thereby use the same facilities for all.

The problem of satisfying the demands for service made on radio relay systems has its roots almost with the birth of such systems. The TD-2 System, introduced in 1950, was the Bell System's first commercial radio relay system. Within a few years, many of its routes were operating at their full channel capacity. The future of radio relay systems clearly seemed to be one of constant growth. To prepare for this future, Bell Laboratories developed the TH and TJ Systems. Even before these systems were developed, Laboratories engineers had designed the horn reflector antenna (RECORD, *November* 1955) and the circular wave-guide associated with it.

TD-2 and TH are long-haul systems operating in the 3700 to 4200 mc frequency band, and the 5925 to 6425 mc band, respectively. TJ, a short-haul system, operates in the 10,700 to 11,700 mc band. The horn reflector antenna is a broadband device that can be operated in all three bands. Furthermore, it is able to transmit or receive signals polarized at 90 degrees to each other.

This antenna, then, set the stage for stacking all three systems on a single route and for further increasing the channel capacity of each system by transmitting dual polarizations of each frequency band. Before this capability could be used, however, a way had to be found to: (1) combine the three common carrier bands so they can be transmitted and received by a single antenna; and (2) combine the two polarizations of each common carrier band. A systems combining network developed at Bell Laboratories accomplishes these vital functions.

A complete systems combining network consists of a series of special directional couplers connected in tandem by means of transducers as shown in the drawing on page 89. There are three

different coupler designs, one for each common carrier band—the 1407A Network for TD-2, the 1406A Network for TH, and the 1405A Network for TJ. Each coupler is a reciprocal network; that is, a systems combining network can combine the three frequency bands and the two polarizations of each band for transmitting, and it can separate the bands and their polarizations for receiving.

Main Components of a Network

An antenna, the circular waveguide run, and a systems combining network make up an antenna system. The combining network mounted at the bottom of a microwave tower, is connected to the antenna by the circular waveguide run. The antenna receives stacked signals of the three common carrier bands and passes them to the combining network. The drawing opposite shows how the directional couplers extract the polarizations of each frequency band in turn. Only one polarization of the TD-2 signal is extracted by the first directional coupler (the 1407A Network) the signals encounter. The remaining energy passes to the next coupler (another 1407A Network), which is rotated 90 degrees from the first, and the second TD-2 polarization is extracted. Next, the TH signals are extracted, in turn, by two directional couplers (the 1406A Network) and only TJ remains. Finally, the 1405A Network separates the two polarizations of TJ. Each polarization is fed through rectangular waveguide to the radio equipment. In transmission, signals travel through rectangular waveguide from the radio equipment, are combined in the networks, and fed to the antenna through the circular waveguide feed system.

Clearly, all parts of the antenna system must be closely integrated. Between the antenna itself and the combining network, the circular waveguide run must provide a good impedance match, low transmission loss, and high cross-polarization discrimination to all three frequency bands. Good impedance matching (i.e., small reflections) and low transmission loss are old, familiar requirements in transmission systems. High cross-polarization discrimination is a measure of the system's ability to prevent the mixing of two orthogonally polarized signals at the same frequency. As the discrimination figure decreases, the coupling of the two signal paths increases. This eventually produces excessive crosstalk.

The minimum return loss of the horn reflector antenna is 40 db. This means that only one ten-thousandth of the power transmitted through the circular waveguide run is reflected back into it

from the antenna. Furthermore, the antenna's cross-polarization discrimination is greater than 40 db.
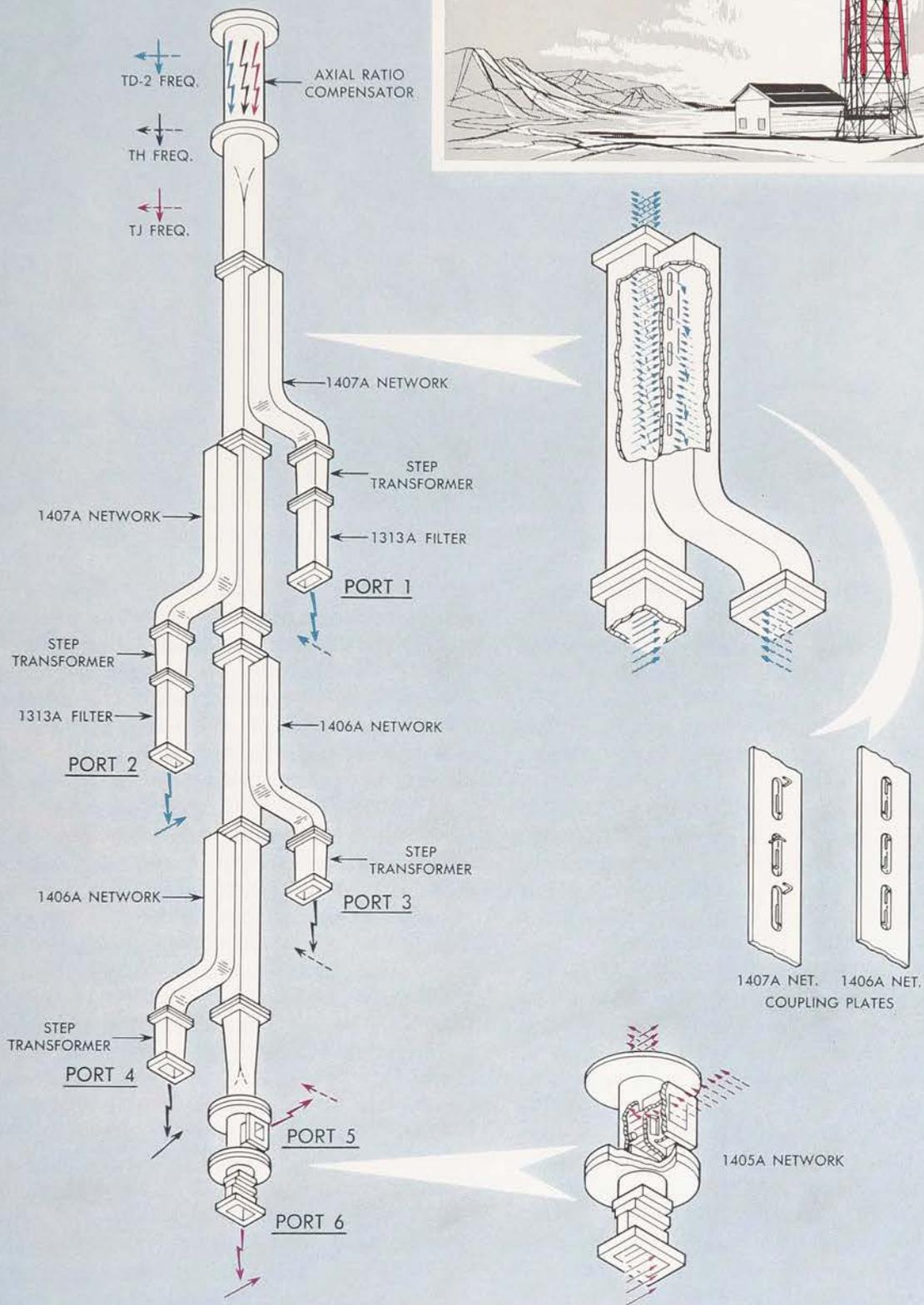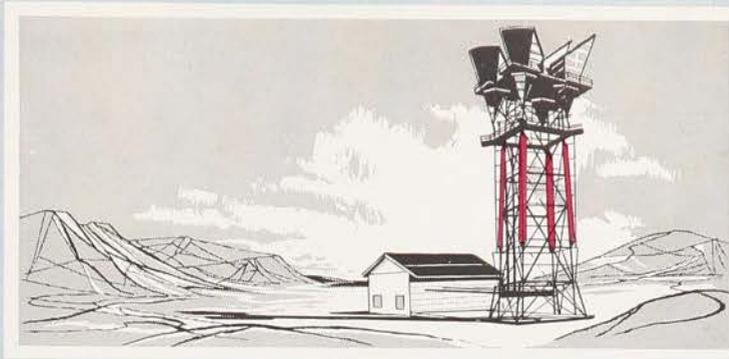
Out-of-roundness and discontinuities in the circular waveguide run can degrade the cross-polarization figure of transmitted and received signals beyond acceptable requirements. An axial-ratio compensator is placed between the circular waveguide run and the combining network to correct this. It consists of a foot long section of circular waveguide that is purposely deformed to provide cross-coupled energy that can neutralize the undesired cross-coupled energy of the antenna and a long waveguide run. Ideally then, two sets of signals polarized exactly 90 degrees from each other are received by the systems combining network. From this point, it is up to the combining network to separate each frequency band and its individual polarizations with a minimum of transmission loss, cross-coupling, and reflection.
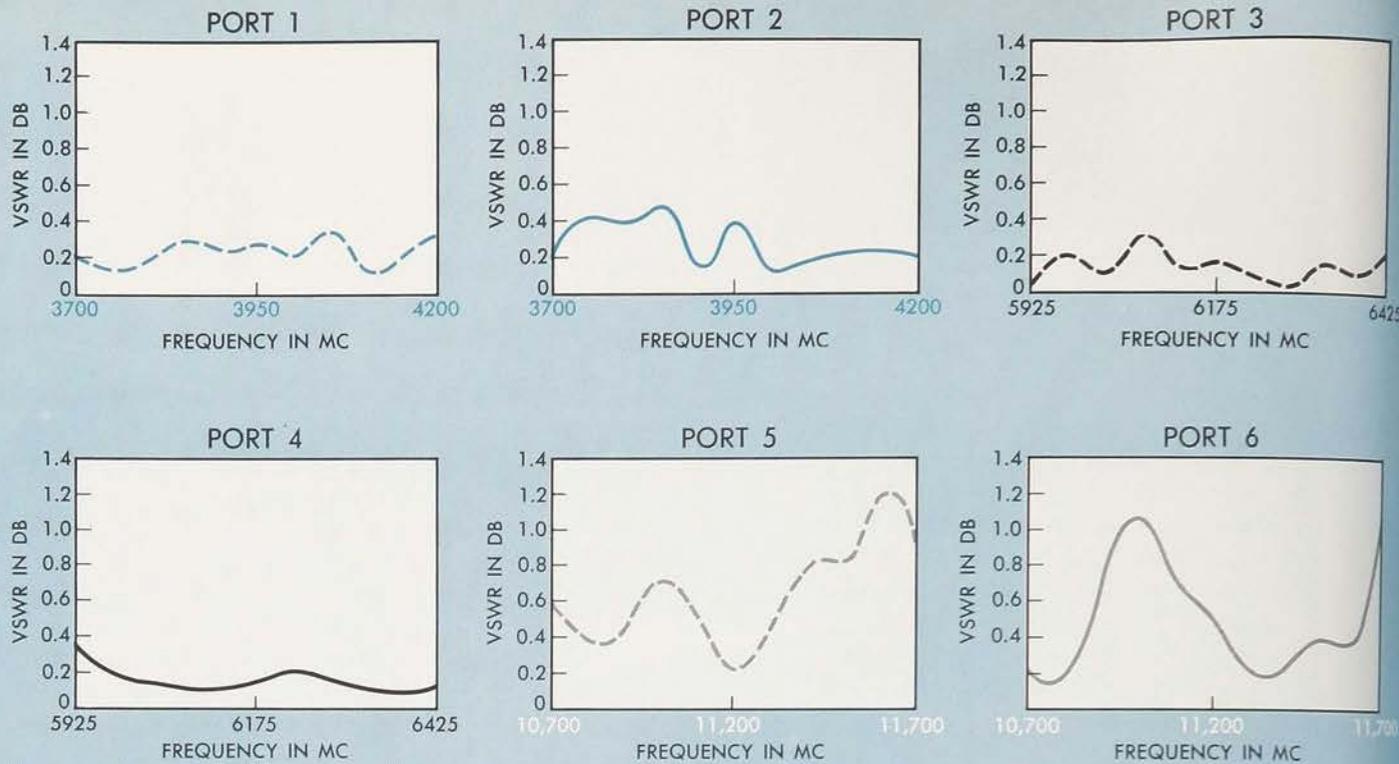
Directional Couplers

The 1407A and 1406A Networks are multi-hole directional couplers. Each has two sections of waveguide—a square section that carries both polarizations of the signals and, adjacent to it, a rectangular dominant-mode section that feeds one stripped-off polarization to the radio equipment. Slots cut in the wall between the two waveguides couple only one polarization of the received signals. Frequency sensitive obstacles placed in or near these slots allow only the wanted frequency band to be coupled through.

The 1405A Network is a polarizer of relatively simple design. Its main waveguide, circular in cross-section, supports both polarizations of the TJ signal. A hole in this waveguide wall couples one polarization into the standard size rectangular waveguide. A septum in the main waveguide allows the other polarization (and only that) to pass straight through to a step transducer. This brings the second polarization from the main waveguide to rectangular waveguide for the run into the radio equipment. Circular waveguide is used in this coupler so that when the network is installed, it can be rotated into the most accurate

The microwave systems combining network is installed close to the base of a microwave tower (inset upper right). As radio signals pass from the antenna to the relay equipment, polarizations of each frequency band are stripped off and coupled to waveguide running to the radio equipment. This drawing shows signals being received; for transmitted signals, the network merely reverses the process shown here.

TD-2 FREQ.

TH FREQ.

TJ FREQ.

AXIAL RATIO
COMPENSATOR

1407A NETWORK

STEP
TRANSFORMER

1407A NETWORK

1313A FILTER

PORT 1

STEP
TRANSFORMER

1406A NETWORK

1313A FILTER

PORT 2

STEP
TRANSFORMER

1406A NETWORK

PORT 3

STEP
TRANSFORMER

STEP
TRANSFORMER

PORT 4

PORT 5

PORT 6

1407A NET.   1406A NET.
COUPLING PLATES

1405A NETWORK

Impedance match (VSWR) of signals at each port of a systems combining network.

alignment with the received signal polarizations.

Precise tapered transducers are used to connect the various shapes and sizes of waveguide in the antenna system. The 7A Transducer connects the circular waveguide run to the square waveguide of the 1407A Network; the 6A Transducer connects the 1407A Network to the square 1406A Network waveguide; and the 5A Transducer connects the 1406A Network to the circular 1405A Network waveguide. Other transducers have been designed to connect directly from the square waveguide of the networks to dominant mode rectangular waveguide, thus providing the system with great flexibility.

Critical to the electrical performance of the systems combining network, is the size of the waveguides that form the directional couplers. The choice of sizes for the square waveguide is severely limited to reduce the effect of mode conversion in the three carrier frequency bands. The square waveguide used in the 4 or 6 kmc couplers can propagate higher order modes of transmission in addition to the desired ones. Many of these modes have cutoff frequencies below 11,700 mc, the highest frequency of the three microwave systems, and thus could produce high reflections, high transmission loss, and high cross coupling. Difficulties with higher-order mode couplings are most likely to occur in regions close to their cutoff frequency. Hence, the dimensions of the

square waveguide are carefully chosen to have cutoffs as far as possible from the 4 kmc, 6 kmc, and 11 kmc frequency bands for all the higher order modes that the waveguide can propagate. The drawing on page 92 shows the relationship between the mode cutoff pattern for 1.790-inch-square waveguide used in the 4 kmc coupler and the common carrier frequency bands.

The size of the rectangular waveguide of the coupler depends on the size of the square waveguide. After the dimensions of the square waveguide are determined, complementary dimensions are determined for the rectangular waveguide so that the phase velocity of the coupled wave remains constant as it passes from the square to the rectangular waveguide. Since the rectangular waveguide is not a standard size, a step transformer is used to match each coupler to the standard size waveguide for each common carrier band.

Power Transfer Between Waveguides

Complete power transfer between the square and the rectangular waveguides is achieved by means of the longitudinal slots cut through the common wall between the two. The number of slots and the spacing between slots is different in each network and is determined by the frequency band to be coupled. The 1407A Network has 16 coupling slots at intervals of less than 1.5 inches. The 1406A Network has 23 slots at intervals

90

PORT 1 — PORT 2 — PORT 3
PORT 4 — PORT 5 — PORT 6

LOSS IN DB / FREQUENCY IN MC
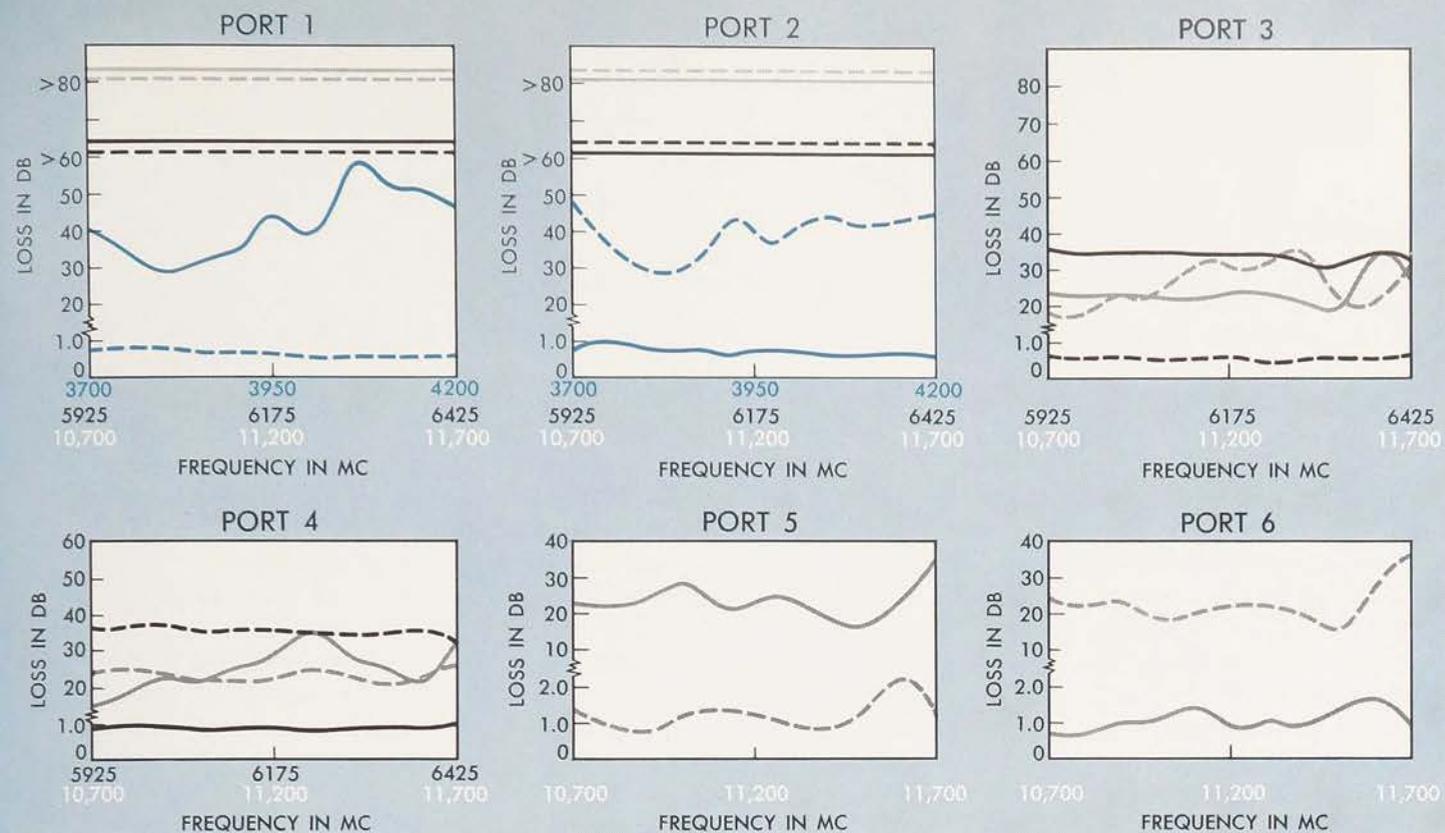
Measured loss characteristics of signal at each port of a systems combining network.

slightly greater than one-half inch. In each network there are two additional slots—one at each end of the line of coupling slots—which improves the impedance.

Actually, if simple slots were used in the 1407A Network some of the TH and TJ energy would be coupled into the rectangular waveguide along with the TD-2 frequency band. Therefore, two sets of wire resonators are placed in the slots as shown in the drawing on page 89. These resonators reduce the coupling coefficients of the slots over the TH and TJ bands to such a small amount that only a few tenths of a db is lost when these frequencies pass through the network.

The resonators in the coupling slots are approximately one-quarter of a wavelength long at 6 kmc to produce minimum coupling in the 6 kmc band. Incidentally, this set of resonators also flattens the coupling over the 4 kmc band and provides adequate decoupling in the 11 kmc band. The second set—perpendicular to the coupling plate and projecting into the rectangular waveguide—improves the impedance over the 11 kmc band. In the 1406A Network similar resonators are used to minimize coupling in the 11 kmc band.

All dimensions of the networks are quite critical. 1406A and 1407A Network components are fabricated from aluminum castings (the Western Electric Company has recently started fabricating these networks from extruded alumi-

num sections) which are machined to maintain a tolerance of ±0.002 inches on the internal waveguide dimensions. To meet coupling and impedance requirements, the length of the coupling slots cannot vary more than ±0.002 inch, and their width must be kept within ±0.001 inch. The resonators must be located longitudinally in the slot to ±0.001 inch, and centered in the narrow dimension within 0.0005 inch.

The curves on this page show the typical measured loss characteristics at each port of a complete systems separating network for each carrier received at the antenna. At port 1, the horizontal polarization of TD-2 frequencies is received with less than 1.0 db loss, while discrimination to the vertical polarization is 28 to 55 db across the band. Loss at port 1 for both polarizations of TH and TJ is greater than 60 db and 80 db, respectively. These figures arise from the combined effects of the 1407A Network and the 1313A low pass filter (see drawing, page 89). The low pass filter passes the TD-2 frequencies with only about 0.2 db loss, but presents a very high loss to TH and TJ frequencies. This added discrimination is particularly desirable in system arrangements which require a TH transmitter to operate on the same antenna with a TD-2 receiver.

At port 2, the vertical TD-2 polarization is received freely, but the network rejects the hori-
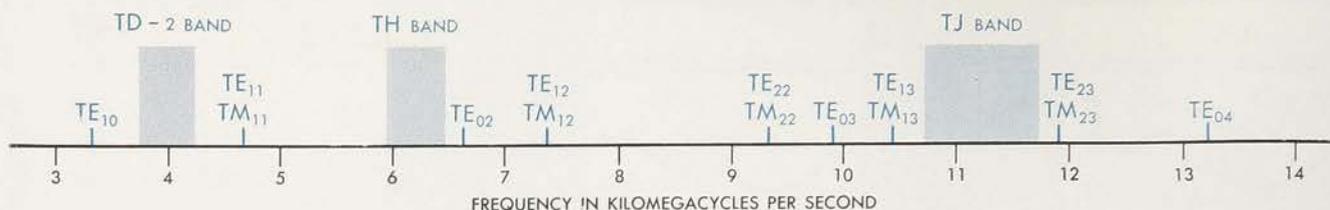
Relationship of the mode cutoff pattern to three common carrier bands for 1.790-inch waveguide.

zontal polarization while, together with the low pass filter, it rejects TH and TJ frequencies.

Ports 3 and 4 act in much the same way to freely transmit the polarizations of TH frequencies while rejecting the TJ band. A low pass filter is not required at these ports because the 11 kmc transmitter power in use, up to now, has been too low to cause interference in a TH receiver connected to the same antenna. TD-2 frequencies are below the cutoff frequency of the waveguide and cannot be propagated at these ports.

Ports 5 and 6 (in the 1405A Network) have a total loss of 0.5 to 2.0 db for the received polarization and from 16 to 35 db for the rejected one. Neither TD-2 nor TH frequencies can be propagated in this network's waveguide.

The curves at the top of page 90 show the impedance match of each port in db VSWR (voltage standing wave ratio). For example, 1.0 db VSWR means that the magnitude of the reflected signal is 25 db below the incident signal and 0.5 db VSWR approximately equals a 31 db return loss.

Because the TJ signals travel the longest path through the combining network and encounter the largest number of discontinuities in the propagating waveguide, they subsequently suffer the greatest degradation of return loss, insertion loss, and cross-coupling performance.

Combining networks are now in operation on many Bell System radio relay routes. Most of the new routes are initially installed with two 1407A Networks. Thus, the route is capable of transmitting two polarizations of TD-2 signals. Later, two 1406A Networks may be added to transmit two TH polarizations. Finally, a 1405A Network may be added to transmit two TJ polarizations.

The system separating network arrangement has proven to be a most effective way to increase the traffic capacity of radio relay routes. The flexibility of the components of a combining network and the compatibility of its electrical performance with the three carrier systems help equip any route to serve whatever traffic demands it may encounter.
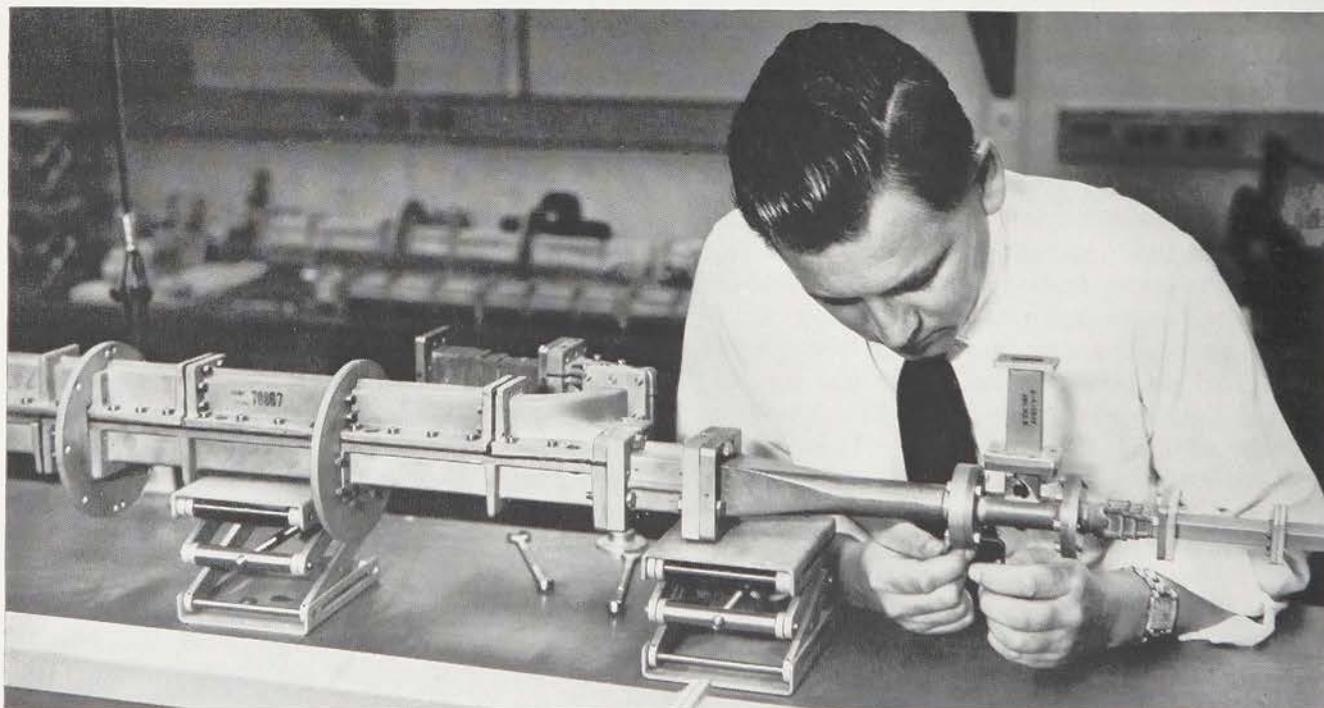
A. J. Alberts adjusting the polarizer for the TJ frequency band on a systems combining network during development of the device at the Merrimack Valley location of the Laboratories.

HIGH-GAIN OPTICAL MASER DEVELOPED

The first high-gain gas optical maser (laser) has been put in operation at Bell Laboratories. The device uses a helium-neon gas discharge which has enough gain at a wavelength of 3.39 microns to become a practical amplifier. Compared to previous gas lasers which gave typical gains of 0.2 to 1.0 db per meter, the new amplifier has achieved gains of up to 50 db per meter. Each of several lines around 3.39 microns has, at this high gain, a bandwidth of 300 mc. This bandwidth can be easily increased at least ten times.

Discovery of the high gain at this wavelength is a result of earlier work by Bell Laboratories scientists which showed that a large inverted population can be maintained between several energy levels of neon in a helium-neon discharge. The information was reported at the Third International Quantum Electronics Conference in Paris in a paper by J. Dane Rigden, Alan D. White, and E. I. Gordon all of the Electron Device Laboratory.

CHEMICAL POLISHING OF GALLIUM ARSENIDE

A method of polishing gallium-arsenide crystals smoother and flatter than ever before has been devised by Miles V. Sullivan and George A. Kolb, both of the Electron Device Technology Laboratory. They use bromine dissolved in methanol as a chemical etchant, together with a rotating polishing wheel like that previously used for electropolishing germanium and silicon. With this combination, all of the common faces of gallium arsenide have been polished at room temperature to smooth surfaces considerably flatter than could be accomplished by ordinary chemical polishing.

The GaAs slices are attached to the surface of a small block and then hand-lapped with 5 micron alumina for about one minute until all the slices are in a common plane. The block is placed close to an 8-inch diameter disk which was covered with a Pellon polishing cloth and soaked overnight in a solution of the bromine-in-methanol etchant.

Etchant is fed to the space between the polishing wheel and the block while the wheel is rotated at about 72 rpm. Stirring the etchant this way increases the etching rate. Different concentrations of bromine are used for different faces of the crystal. It takes about 30 minutes to polish the GaAs to within one micron flatness. The average surface roughness is $\pm$ 20 angstroms.
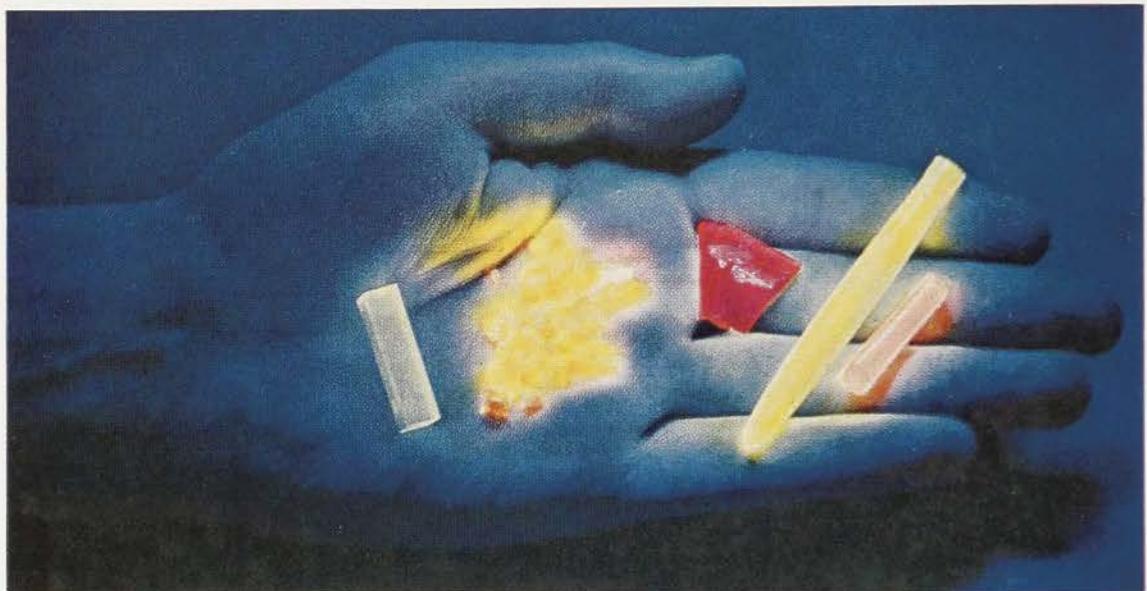
Optical maser crystals are shown first in daylight and then in ultraviolet light. Fluorescence indicates that a crystal may produce maser action. When masing, this fluorescence is "harnessed" and emitted as a high intensity beam of coherent, monochromatic light. The crystals shown are (l. to r.) zoned fluorite, flux-grown scheelite, flux-grown ruby, and two scheelites pulled from the melt.

*Crystal growing—long a jeweler's concern—
has recently commanded much scientific
attention. Now, as maser research gains
momentum, scientists are producing many
new crystals capable of optical maser action.*

Crystals for Optical Masers

Kurt Nassau

SENDING MESSAGES far into space, drilling holes in a diamond, performing operations on the eye and carrying many thousands of telephone conversations simultaneously—these are the possibilities of the beam of light from an optical maser. In the three years since the first demonstration of optical maser (laser) operation, some three dozen materials able to provide laser action have been discovered. Most of these will operate on a pulse basis only, but thirteen gases and four of the solid state materials will provide continuous (C.W.) operation.

In the case of gaseous masers (RECORD, *July-August*, 1962), a quartz tube is filled with the gas or mixture of gases required; the only "materials" problem involves the question of adequate purity, and for this purpose standard gas purification methods appear to suffice. In the case of solids, however, each individual composition, at each concentration to be tested, must be more or less laboriously prepared by one of the various techniques of crystal growth. The availability of large crystals having high perfection is one of the limiting factors of solid state optical maser research at present.

A solid state maser material consists of an active ion, such as trivalent chromium, having electrons in a partly filled shell which can be excited into higher energy states by the absorption of energy. This is followed by the re-emission of part of the absorbed energy in the form of light, producing fluorescence. The active ions are held in the lattice positions of a crystalline material such as aluminum oxide (Al_2O_3). (Chromium in aluminum oxide is ruby, the earliest and still most widely used optical maser material.) The crystal field created by surrounding atoms produces splitting of the energy levels of the active ion and thus affects the emission wavelength. If the sites into which the active ions enter are all crystallographically equivalent, the result can be a simple set of sharp emission lines. If there are many types of sites, such as in a glass having semiordered structure, a broad emission band is the usual result.

It is possible to specify in mathematical form the exact requirements for a fluorescent material to operate as an optical maser. Determination of the parameters involved will indicate whether laser action can occur, but considerable effort is required to accumulate the necessary data for the computations. In actual practice, one searches first for materials which have intense fluorescence in a few relatively narrow lines at a wavelength

ACTIVE ION	WAVELENGTH & MAX. TEMP.		HOST LATTICE
Cr^{3+}	0.7μ	R.T.	Corundum*
U^{3+}	2.5μ	L.N.	CaF_2^*, SrF_2, BaF_2
Pr^{3+}	1.1μ	L.N.	$CaWO_4$, $SrMoO_4$
Nd^{3+}	1.1μ	R.T.	Sch.**, Fl., Glass
Ho^{3+}	2.0μ	L.N.	$CaWO_4$, CaF_2, Glass
Er^{3+}	1.6μ	L.N.	$CaWO_4$
Tm^{3+}	1.9μ	L.N.	$CaWO_4$, CaF_2, SrF_2
Yb^{3+}	1.0μ	L.N.	Glass
Sm^{2+}	0.7μ	L.N.	CaF_2, SrF_2
Dy^{2+}	2.4μ	L.N.	CaF_2^*
Tm^{2+}	1.1μ	L.H.	CaF_2

HOST LATTICE	ACTIVE ION	PREPARATION METHOD
Corundum (Al_2O_3)	$Cr^{3+}*$	Verneuil, Flux
Fluorides $(CaF_2, SrF_2, BaF_2, LaF_3)$	$U^{3+}*$, Nd^{3+} Ho^{3+} Tm^{3+} Sm^{2+}, $Dy^{2+}*$, Tm^{2+}	Bridgman Czochralski Zone
Scheelites $(CaWO_4, SrMoO_4,$ etc.)	Pr^{3+}, $Nd^{3+}**$, Ho^{3+}, Er^{3+}, Tm^{3+}	Czochralski
Glass	Nd^{3+}, Ho^{3+}, Yb^{3+}	Glass Melt

*Continuous operation at L.N.

**Continuous operation at L.N. & R.T.

Abbreviations
R.T. —Room Temperature
L.N. —Liquid Nitrogen
L.H. —Liquid Hydrogen
Sch.—Scheelites
Fl. —Fluorides

The upper table lists known optical maser materials by active ion. Below are host lattices with the active ions which convert them into maser materials, also preparation methods applicable to each.

at which absorption is small.

The classical point of departure for any such search is the work of the early mineralogists who observed and recorded the fluorescence of natural materials. It is thus not a coincidence that the three major groups of host lattices are based on naturally occurring fluorescent minerals, namely corundum (Al_2O_3), fluorite (CaF_2), and scheelite $(CaWO_4)$. Of course the impurities found in nature are limited to relatively few active ions, and natural crystals are usually too impure and imperfect to warrant consideration for optical maser experiments. Accordingly, it is necessary to make synthetic material containing the desirable active ions. In the case of scheelite, for example, L. G. Van Uitert of the Laboratories grew small crystals and studied the fluorescence resulting from various active ions. When a material looks promising, the most practical approach is to synthesize a relatively large crystal and test it for optical maser action.

Problems in Crystal Synthesis

Here unusual problems face the chemist. It is relatively easy to grow crystals of microscopic dimensions of most substances. Sizes up to 1/10 inch are somewhat more difficult to prepare. For optical maser work, however, crystals of about one inch in length and of high optical perfection are needed. In addition, one must anticipate future demands for crystals from several inches to more than one foot in length. Accordingly, it is expedient to investigate first crystals which can be grown in large sizes. At the same time, work must continue on the growth of promising materials which cannot yet be grown in large enough crystals.

In the crystals that can be grown, several types of imperfections occur. The size of these imperfections ranges from the macroscopic or visible to the submicroscopic or atomic, the latter being inferred indirectly by a variety of experimental techniques.

On the macroscopic scale there are solid or gaseous inclusions, seen by eye or under the magnifying glass, and optical inhomogenities due to strain, revealed by the interferometer and sometimes under polarized light. These types of imperfections absorb or scatter light and thus increase the power requirements of an optical maser.

At the other extreme are atomic scale imperfections in the immediate neighborhood of individual active ions. Since the crystal field experienced by the ion affects the energy levels, any random irregularities will produce an increase of the fluorescent linewidth. This may be caused, for example, by the presence of sufficient quantities of other impurities. In going from an ordered structure such as $CaWO_4$ to the partially disordered $Na_{1/2}Gd_{1/2}WO_4$, where the monovalent sodiums (Na) and trivalent gadoliniums (Gd) take the place of the divalent calciums (Ca) in a random fashion, line broadening is also observed.

Charge compensation is necessary when the active ion entering a lattice site has a valence different from the ion it replaces. In the case

of ruby, where trivalent chromium replaces trivalent aluminum in Al_2O_3, charge compensation is not necessary. But when a trivalent ion such as neodymium replaces divalent calcium in CaF_2 or $CaWO_4$, the excess positive charge must be compensated for in some manner. The compensation mechanism is usually determined by additions or atmosphere control during crystal growth.

The physicist or communications engineer concerned with optical masers is more interested in the active ion than in the host lattice. Except in ruby, the frequency of the output light depends primarily on the active ion, since the energy levels from which it derives are affected only to a minor extent by the crystal field of the lattice. The maximum temperature of operation in most optical masers again depends on the ground state splitting of the active ion and is little affected by the lattice. On the facing page, presently known optical maser materials are listed by active ion. The approximate wavelength in microns $(1\mu = 0.000039$ inches) and the maximum temperature of successful operation are also included.

To the chemist it is the host lattice which presents the challenge; in most cases the active ion adds only minor complications to the growth problems. The exceptions are the variable valency ions where special techniques have to be used to produce the species required. In the table are also grouped the host lattices with those active ions which convert them into optical maser materials. Also indicated are the methods of preparation applicable to each material. There are other techniques which can be used, but only those yielding crystals of a size and perfection adequate for maser use are considered here.

Characteristics of Melt Growth

With the exception of the flux growth of corundum, all the other optical maser materials presently used are grown from the melt. As such, there are certain characteristics that these methods have in common.

A major advantage of growth from the melt is that since the melt is essentially the same composition as the crystal to be grown, impurities derived from a solvent are absent. Also, growth is very rapid, being of the order of a few hours per inch rather than days per inch as in other growth techniques. Opposing these advantages are two main disadvantages: growth takes place at the melting point, requiring very high temperatures of often over 3000 degrees F; the range of this type of growth technique is somewhat limited. Among the criteria involved are a con-

gruent melting point, absence of destructive phase changes, reasonably low vapor pressure and viscosity, and in some cases the availability of an inert crucible material which can tolerate both the melt and the atmosphere required.

Active Ion Distribution

When a crystal is grown from a large volume of melt containing a given amount of an active ion, the crystal will, in general, contain a different amount of active ion. For example, a melt of calcium tungstate with 1.0% neodymium yields a crystal containing only 0.27% neodymium. This value of 0.27 is termed the distribution (or partition) coefficient k. Distribution coefficients vary with host lattices and active ions, and are even affected by the addition of other ions. Thus charge compensation by the addition of excess sodium to the melt in the above example will increase the k to 0.86 and change the crystal field.

If the relative volumes of grown crystal and melt change appreciably during growth, as in some melt techniques, large concentration gradients can occur in the crystal when k is not close to unity. When the melt volume is very small, as in the Verneuil method, slight irregularities in the temperature can again produce large concentration changes.

The glasses listed in the table are made by conventional glass melting and casting techniques and will not be further discussed. Each of the other methods is described for one of the optical maser materials for which it has been successfully used.

When materials are zone melted, the product is frequently a single crystal. Accordingly, this technique, perfected by W. G. Pfann at Bell Laboratories, can be used for crystal growth. The Bridgman technique originated by P. W. Bridgman in 1925 is closely related; both methods are well suited for the growth of fluorides and have been used for this purpose by H. J. Guggenheim at the Laboratories.

In the Bridgeman growth of fluorides (e.g. fluorite—CaF_2), the starting material is melted in a platinum crucible having a pointed tip at the lower end. The crucible contents are solidified starting from the tip; since there is only one point of nucleation, a single crystal usually results. The CaF_2 is first completely melted in the upper part of a double furnace, which is held a few degrees above the melting point. The crucible is then slowly lowered into the lower furnace, which is kept at a temperature somewhat below the melting point of CaF_2.

The furnaces are resistance heated and con-

Calcium tungstate-neodymium crystals are grown by slowly pulling the crystal from a melt (Czoch-ralski Method). Here, reaching around a safety screen, the author takes a melt sample for analysis.

trolled to maintain very steady temperatures. Since molten fluorides react with oxygen, provisions for atmosphere control must also be made. It is possible to scale up this process so that crystals many inches in diameter may be grown.

In the zone technique, a graphite boat of perhaps one inch in diameter and one foot long is used. Here only a small region less than one inch in length is melted by coupling radio frequency energy directly into the crucible from a water cooled copper coil. Typically, a 450 kilocycle generator is used to supply the coil with about five kilowatts of power. Moving the molten zone from one end of the boat to the other converts the contents into a single crystal.

Another technique was originated in 1918 by J. Czochralski, who reported the growth of single crystals of metals by pulling from the melt. Since then it has been extensively used for the semiconductors silicon and germanium, originating with G. K. Teal, J. B. Little and E. Buehler at

the Laboratories. This technique was also shown to be applicable to oxide systems by the author, and single crystals of calcium tungstate (scheelite) and related materials have been grown for optical maser use.

The same method has been extended to other compounds having the scheelite or related structures by L. G. Van Uitert and co-workers at the Laboratories. It has also been used by H. J. Guggenheim and the author for the growth of fluorides. Atmosphere control must again be provided in this latter case.

The growth of calcium tungstate is shown above. The melt is held at a temperature of about 2930 degrees F. in air, and at this temperature the only practical crucibles are those made of the precious metals, rhodium or iridium. The crucible is typically two inches in diameter and of equal height; 10 kilowatts of radio frequency energy at 450 kilocycles are required to heat it. The power is coupled directly into the crucible

wall, where resistance to the current produces the heating.

When the temperature is steady, a seed crystal is inserted into the melt surface, and, as additional material solidifies onto it, it is withdrawn slowly and steadily. It is also rotated so that a uniform cylindrical crystal is obtained. By this means calcium tungstate crystals as long as 18 inches and more than one inch in diameter have been grown.

Continuous operation in a solid state maser was first observed in calcium tungstate-neodymium (RECORD, *February*, 1962) and this is still the only solid state maser to operate continuously at room temperature.

Two techniques are used to grow corundum (Al_2O_3) containing chromium, more commonly known as ruby. The Verneuil, or flame fusion method has been used since the eighteen nineties for the production of jewelry grade rubies and sapphires. Finely divided alumina powder containing the desired impurities is sprinkled into a hydrogen-oxygen flame. As the particles fall through the flame and collect in a cap on the growing crystal, they first melt and then solidify again. A complex technology has recently grown up around this process with a number of modifications designed to improve crystal perfection.

The flux growth of ruby is one of a number of solution procedures worked out by J. P. Remeika at Bell Laboratories. In a typical preparation, alumina and chromium oxide are dissolved in a lead oxide—boron oxide solvent in a platinum crucible at about 2400 degrees F. Crystals are formed by slowly cooling the crucible, since solubility decreases at lower temperatures and not as much ruby can be held in solution. By the careful control of conditions, a small number of fairly large (over ½ inch) rhombohedral crystals can be grown. Occasionally, flat faces of such perfection are formed that these can be silvered and maser action obtained without the necessity for polishing.

Although many distinct crystal growth techniques are described in the literature, the criteria for the choice of the one most likely to work are generally not known when a new compound is being considered. In addition, major modifications are almost invariably necessary to adapt a given method to the specific properties of the material. These factors make crystal growth more of an art than a science. It is hoped that the continuing study of growth mechanisms, charge compensation, etc., which accompanies crystal preparation will ultimately lead to a better understanding and a more rational approach to crystal growth.

Development Contractor Named For Sprint Missile

The Army has approved selection of Martin-Marietta as development contractor for the Sprint missile, planned as a major component of the Army's NIKE X anti-missile missile system. Martin-Marietta will join the Army's NIKE X development team as a subcontractor to Bell Telephone Laboratories, which has responsibility for system design and development. The Western Electric Company is the system prime contractor. Amount of the initial subcontract, which is being negotiated between Bell Laboratories and Martin-Marietta, will be approximately $5,000,000.

Selection of the Sprint subcontractor as the one best meeting the needs of the Army resulted after extensive review by Bell Laboratories and the Army's NIKE ZEUS project office at Redstone Arsenal, Alabama.

Martin-Marietta was one of three prospective Sprint subcontractors chosen last fall who performed paid, 120-day studies. These contractors were selected after a thorough review of more than 40 defense contractors. Douglas Aircraft Company, Martin-Marietta, and North American Aviation submitted the results of their studies on February 1 for detailed evaluation by Bell Laboratories and the NIKE ZEUS project office.

Development of the Sprint missile will be a part of the redirected NIKE ZEUS program, first announced in January by Secretary of Defense Robert S. McNamara, who indicated that the advanced version of the NIKE ZEUS, called NIKE X, would incorporate the Sprint, advanced radars and components of the current ZEUS system. (See page 78 of this issue for an over-all article on the NIKE ZEUS system.)

Col. I. O. Drewry, NIKE ZEUS project manager, who is also directing Army efforts on the NIKE X, said that Sprint will complement, not replace, the NIKE ZEUS missile. The Army said the Sprint would be shorter and lighter than the 48-foot long NIKE ZEUS missile and would use a solid-fuel rocket propulsion system.

A major feature of the Sprint design is the emphasis being placed on extreme acceleration characteristics enabling the Sprint to reach intercept altitude in less time than the current ZEUS missile, which with its 450,000-pound thrust first-stage booster is already the fastest air defense missile ever developed in the Free World.

The Army said initial testing of the Sprint missile would be carried out at White Sands Missile Range, N. M., with subsequent firings planned at Kwajalein Island in the mid-Pacific.

The 6A Impulse Counter monitors impulse noise
in a circuit completely automatically, freeing
craftsmen for more challenging tasks.

The use of voice circuits for data transmission is growing rapidly. To meet the noise control requirements of this new service, Bell Laboratories engineers have introduced a device that gives a measure of impulse noise accurately and automatically.

The 6A Impulse Counter

D. L. Favin

FACED WITH INCREASING DEMANDS for data transmission service, the Bell System is making every effort to adapt its facilities accordingly. Circuits that were originally designed for voice signals now serve for data transmission as well. Because the new service increases the range of required noise control, Bell Laboratories began to search for an effective means of detecting and measuring system noise. As a result, the Exchange Transmission Laboratory has recently developed a device for counting noise impulses, the 6A Impulse Counter, which is specifically designed for rapid and efficient use on a large variety of voiceband data circuits.

Regardless of the communication facility used or the form of signal transmitted, noise is always a problem. In analyzing a system, an engineer asks what kinds of noise exist and which of these kinds might interfere with the signal he wishes to transmit. In circuits carrying voice signals, for example, continuous background noise is found more annoying than intermittent clicks or pops. But the latter can be disastrous to a data signal transmitted over the same facility. A manufacturer who had ordered 20,000 tons of coal might—because of a noise impulse—find himself inundated with 200,000 tons. Measuring impulse noise is thus quite important if adequate data transmission is to be possible.

Before the design of the 6A Impulse Counter, the only available method of making impulse noise measurements involved a peak reading voltmeter and a 3A Noise Measuring Set. The 3A Noise Measuring Set is used to terminate the line and to provide frequency weighting and amplification. The output of the 3A set is connected to the input of the peak meter. The peak meter "remembers" the peak value of any input signal. This value is displayed on a meter and must be recorded manually. A manual reset control allows the "memory" to be cleared so the set may investigate the amplitude of additional impulses.

Information obtained by this procedure is analyzed according to the particular type of data signal that is to be transmitted. For a given data signal, the requirement will be that the nth largest reading (for example, the 70th largest) obtained in a specified period (say, one hour) shall not exceed a specified level. The record must be examined to determine which impulse was the nth largest, and the amplitude of this particular impulse compared with the specified level. If its value falls below the reference level, then the system is suitable for data transmission. If the nth largest impulse reading is larger, the error rate would be excessive and the system unsuitable for the transmission of that signal.

From this description the older method can be seen to be extremely tedious. A man must observe a meter for a certain period of time,

The author adjusts the new impulse counter before measuring its performance against a test circuit.
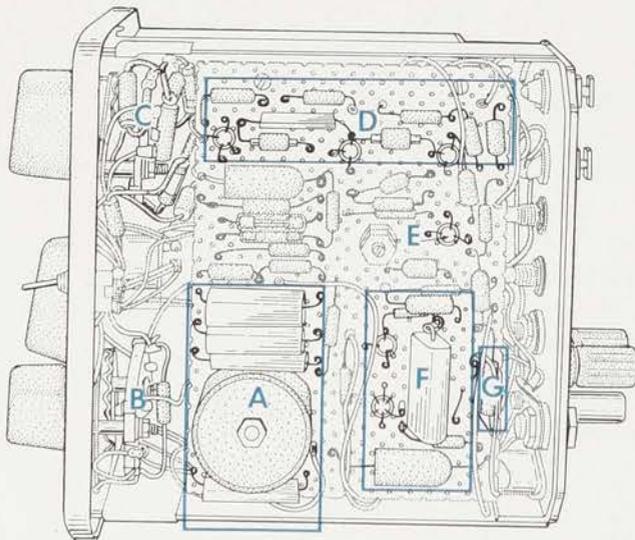
Outlined on this interior, bottom-view sketch are major components and subgroups: (A) input filter, (B) filter-select switch, (C) input attenuator, (D) amplifier, (E) phase inverter, (F) monostable trigger circuit, and (G) relay driver transistor.

record the value of each impulse noise peak, and reset the instrument after each reading. Furthermore, some impulse readings may be lost because they occur before the meter has been reset. It follows that to test all the data circuits in this manner would be expensive and time-consuming. The very monotony of the task inevitably leads to inattention and errors in recording the measurements of noise impulse.

The simplicity and repetitiousness of the job suggest than an instrument might make the measurements completely unattended. The instrument would count the number of impulses that exceed a preset level for a preset period of time, store the number in a mechanical counter, and after the prescribed time, turn itself off. The data obtained this way, while not as detailed as that collected by the previous method, nevertheless accomplishes the same purpose. Previously, the level at which the nth highest impulse level occurred was noted. Emphasis was placed on the level as compared to a required system impulse level. Now the number of impulses above the required system level is counted. If this is less than n, then the system is suitable for data transmission.

Because an automatic instrument is much faster than the manual method of recording peaks, it will count many more peaks. Hence, new limits for the number of peaks allowed have been established.

The new impulse counter performs its job in the following manner: A level switch is set at the system's prescribed level criterion. The far end of the line is terminated and the near end is connected to the input terminals of the set. A filter-select switch is set to the type of weighting desired and a timer is set to the time duration of the test. The test is then started. No further attention is required, for the instrument will record the number of impulses exceeding the preset level and at the conclusion of the test turn off. During this period of time the craftsman is free to accomplish other assigned tasks.

Here then is a transistorized, battery-operated, 4″ x 5″ x 5″, 5-pound instrument that can rapidly detect circuits which are troublesome with respect to impulse noise. It can count impulses at a rate greater than 10 per second over a range from 30 dbrn to 90 dbrn. Hence, it can take data approximately 10 times faster than previously used methods. It stands as an example of how a routine craftsman's job can be fully instrumented, leaving him for tasks that require analysis and understanding.

Waffle-Iron Construction Promises Compact, High-Speed Memory Device

A new magnetic memory device that looks somewhat like a miniature waffle iron has been developed at Bell Telephone Laboratories. Because it has one of the shortest storage paths for a single bit of any magnetic memory device, the structure is extremely compact, and can operate at high-speed on low input power.

The new memory will be particularly useful for large-capacity, economical stores operating at read-write cycles of less than a microsecond. It looks promising for computers and switching systems which are now using ferrite cores and thin films.

The basic waffle-iron device resulted from investigations by James L. Smith of the Solid-State Device Laboratory. It consists of a base plate made of a high permeability ferrite in which a grid of slots is cut, leaving a regular array of rectangular posts. This gives the surface the appearance of a miniature waffle iron.

Preprinted wiring patterns—a set for the read-write and a set for the digit-sense wires—are placed in the slots. An overlay of square-loop magnetic material, such as a type of permalloy, is laid across the tops of the posts.

Information is stored in the overlay material between the posts in the direction of magnetization of the magnetic flux. The width of a slot is the effective length of the magnetic path in the storage material. The high permeability base and the square-loop material connecting a pair of posts form a closed magnetic flux path. One type of waffle-iron memory has posts 100 mils long and 30 mils wide and a slot width of 30 mils.

Both destructive and nondestructive waffle-iron memories have been built; the basic difference is in the magnetic overlay. Destructive memories use an overlay of a single magnetic material. Nondestructive memories use an overlay of two magnetic materials—one for storage and the other for sensing. When a nondestructive memory is read only the sensing material is switched; thus the memory can be interrogated indefinitely without affecting the stored information stored therein.

Another form of waffle-iron memory, called the cubic, has been developed by Andrew H. Bobeck, also of the Solid-State Device Laboratory. In the cubic structure both the selection and sense wires follow straight paths, instead of weaving around the posts as in the other waffle-iron memory. Also, since these wires cross each other at right angles, a pulse traveling down one wire will not induce appreciable current in the other, thus the signal-to-noise ratio is improved. The cubic waffle-iron memory has a very fast read-write cycle; it can be made very small and can be assembled simply.

One experimental memory matrix of the cubic type has a capacity of 128 words of 30 bits per word. It has a read-write cycle time as fast as 200 millimicroseconds. The highly polished ferrite base plate used in this design is slotted to form a grid of 5-mil slots, each 10 mils deep, and spaced 15 mils apart. This matrix has a storage density of 1100 bits per square inch. The 5-mil slot width, combined with an overlay material that has a high switching-threshold, gives fast switching with modest currents.
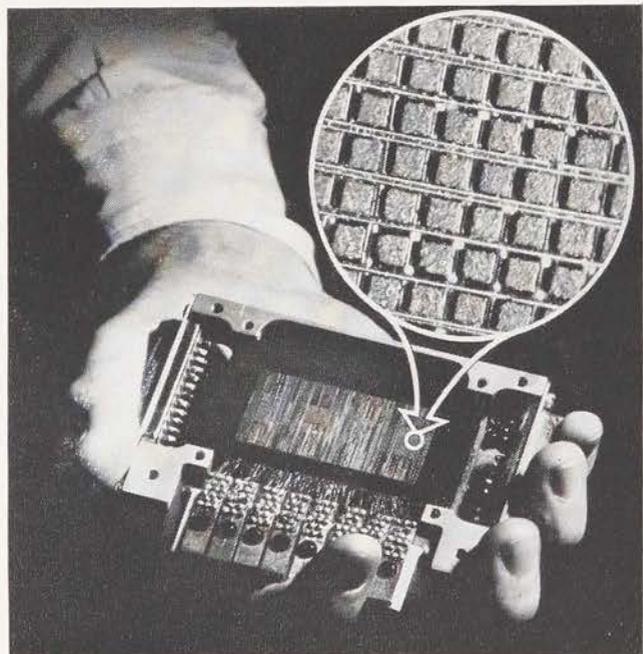

The experimental "Waffle-Iron" memory device can store 64 words of 30 bits per word. It has a storage density of 1100 bits per square inch.

New Switching Network Developed For Government Agencies

A new nationwide communications network which features economy, flexibility and reliability of operation, has been developed by the Bell System for the Federal Government. It is known as the Federal Telecommunications System. It is a private switching system engineered to consolidate the communications requirements of civilian agencies of the Federal Government that are widely dispersed in distance but closely related in function and interests. Initially, it will link over 400 tributary PBX's in 42 cities from four switching centers.

The system is under the supervision of the Government's General Services Administration. A major attraction to GSA was attaining a fast, efficient network for day-to-day communications needs, which also would be survivable—an advantage critically important in times of emergency when vital lines of communication must be maintained. For although the system will be serving civil agencies, many of the agencies would be called upon to perform essential work in the event of national crisis.

An order for switching service was received from the GSA last March, and the project was placed under the direction of the Government Communications Office in Washington, D. C., a Long Lines organization. As with most large-scale communications projects, however, the work soon called forth the efforts of all Bell Companies.
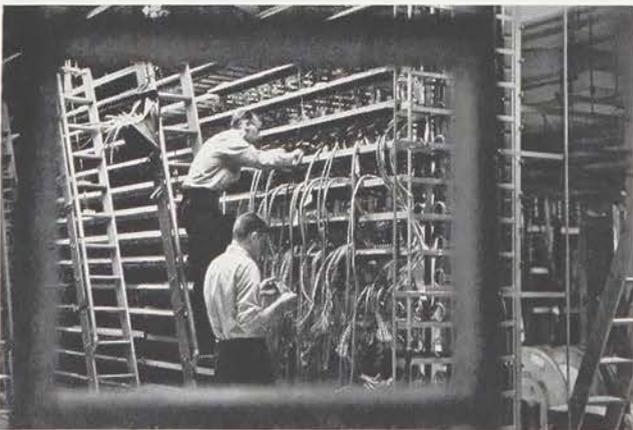
Western Electric's G. Turner (top) and T. Mueller butt cable and separate binders for Federal Telecommunication System installation.

The broad plan for FTS envisions the eventual interconnection of practically all government agencies and is divided into two phases. "Phase I" includes those agencies located in 42 of the major metropolitan centers of the country. "Phase II" carries the plan to a total of 355 cities. Despite the disparity in numbers, Phase I was the greater challenge, partly because it had to be completed in less than one year. Cutover of Phase I occurred on February 15.

The "195 GSA Consolidation Committee" has acted as liaison between Long Lines and the associated companies and also has assisted Long Lines in coordinating the many schedules that are involved in the nationwide undertaking. To facilitate matters, each associated company—including Bell Telephone Laboratories and the Western Electric Company — is represented on the committee by an "FTS coordinator."

In describing the project, P. L. King of A.T.&T.'s Traffic Division said, "In connection with the FTS the GSA functions much like a common carrier—that is, for the other agencies of government, for the Postal Department, Internal Revenue, V. A. Offices, and so on. It operates between the agencies and the telephone companies, handling the necessary business arrangements for telephone service and billing the agencies for whatever service they use."

Broadly, the FTS network will operate as follows: Phase I of the plan will accommodate voice transmission—roughly 65 per cent of the agencies'' Long Distance telephone traffic will travel over the leased network. Eventually, with Phase II, all 2,500 offices in the 355 cities will have access to the network. The 400 tributary PBX's in the 42 cities of Phase I will be connected to four main switching centers, although additional offices or centers will be added by the Bell Companies, as required, to keep pace with growth.

Direct inward dialing within the FTS network is provided for each centrex and dial PBX included in this network. Termination of the access lines from the No. 5 home office will generally be at one PBX in each city served. This PBX will be known as the serving PBX and will usually be the main GSA PBX in that city. There may be a few cases, however, in which manual terminations may be provided on the cutover date, but conversion to DID will be made as soon thereafter as possible.

As for outgoing calls on the FTS network, these will be placed through an attendant at the serving PBX so that she may ticket and time each call for allocation of expenses to the participating agencies.

news in brief

Telstar Fails To Respond To Commands

Telstar is again failing to respond to commands from the ground, Bell Telephone Laboratories announced on February 28.

The Bell System's experimental communications satellite had worked normally since engineers at Bell Laboratories devised a special coded command that helped overcome an earlier difficulty and restored operation on January 3.

On February 21, Telstar apparently misinterpreted a command and disconnected its storage batteries. Efforts are continuing at Andover, Maine, and Cape Canaveral to correct this difficulty but the satellite is not now transmitting any signals.

The pattern of the present malfunction in many ways resembles that of late 1962. Steps taken to correct the 1962 difficulty were repeated and were successful for a while.

Because of this pattern of response and because of the cyclic pattern of radiation which Telstar encounters, engineers at Bell Laboratories suspect the continued inhibiting effects of radiation on transistors is causing the present difficulty.

The satellite's orbit takes it through three-month cycles of increasing and decreasing exposure to high-energy radiation. Both the present and the earlier difficulties occurred on the uptrend. If radiation is the cause, it is possible that Telstar will recover again during the downtrend it is now entering.

Large Zinc Oxide Crystals Grown From Seeds

Large crystals of zinc oxide now can be grown by the hydrothermal method. In this easily controllable process, zinc oxide crystallizes onto a seed plate which is hung in a dilute basic solution at high temperatures and pressures. The crystals grew in silver-lined chambers, called autoclaves, at 350 degrees C and 8000 psi. Robert A. Laudise, Ernest D. Kolb and Anthony J. Caporaso, all of the Crystal Chemistry Research Department, were able to grow the crystals up to $\frac{3}{8}$-inch in thickness by $\frac{3}{4}$-inch in width, larger than any grown by other methods.

The crystals have desired electrical and acoustical properties. Zinc oxide is both a semiconductor and piezoelectric. Acoustic waves can be amplified directly in it by a method first suggested and carried out at Bell Laboratories by Andrew Hutson, James McFee and Donald White. Because this crystal is so strongly piezoelectric, several times more than quartz, it can be used as a transducer in ultrasonic delay lines.

Fastener Study

A recent study by a Switching Apparatus group at Bell Laboratories has shown that a simple screw fastener will hold longer than most locking devices. In vibration tests, a well-tightened screw held longer than either a similarly tightened screw with a tooth-type washer or a high friction screw.

Tightness in a fastener is primarily a result of longitudinal tension on the screw or bolt. Looseness most often results from shrinkage or deformation of the fastened material so that tension is lost. A split-ring lockwasher stores up energy to counteract this loss; most other locking devices are designed to increase the friction of turning.

Bell System usage has been in general accord with these findings.

A.T.&T. Annual Report Highlights Labs Developments

The year of Telstar was a good one for the Bell System, according to A.T.&T.'s 1962 annual report. The report listed a record construction program—nearly $3 billion — increased earnings per share, and several significant technical and service advances, including Telstar, and Dial TWX among many others.

Of all the work done by the Bell System in 1962, "none was more significant than that attending the Cuban crisis," the report stated. The Bell System's immediate response to the additional communications demands for military needs during this all-out undertaking called attention again to the need for an organization with wide resources, in which unification of operations, manufacture and supply is indispensible to superior performance.

In discussing technical advances, Mr. Kappel said "The Telstar experiment was a notable first for the United States and for business enterprise in the peaceful use of space." Its success, he said, has opened the way to development of a commercial satellite communications system, and provided "basic assurance" that the design of commercial satellites can be undertaken as a straight engineering project.

Greater operating efficiency, Mr. Kappel also said, "is extremely important." Such efficiency contributes heavily to operating savings and better customer service. Examples of such operating efficiency listed in the report included:

A new test set, and a new technique for splicing wires—each of which will produce operating savings of several million dollars a year; and a new undertaking—to be introduced gradually—whereby most local telephone lines can be permanently assigned to specific addresses, eliminating the costly job of rearrangement when telephone users move from one address to another.

W. O. Baker Selected As 1963 Perkin Medalist

Dr. William O. Baker, Vice President—Research, Bell Telephone Laboratories, has been selected as the Perkin Medalist for 1963 by the Society of the Chemical Industry, American Section. The medal, one of the top awards in American chemistry, was presented at the annual Perkin Medal Dinner on February 1st.

Dr. Baker has had a distinguished career as research physical chemist and scientific administrator. He received his B.S. from Washington College in 1935, and the Ph.D. from Princeton University in 1938. He joined Bell Laboratories in 1939, specializing in the study of macromolecules and their solid state properties. Dr. Baker holds more than a dozen patents in this field, including a recent one on a method of increasing the strength of solid rocket fuels. His research led to the use of polymers as ablative nose cones and heat shields for re-entry vehicles for missiles and satellites.

Dr. Baker participates in numerous scientific and educational organizations and for many years has served in consulting and advisory capacities in the Federal government. He is a member of the National Academy of Sciences, the National Science Board, NSA Scientific Advisory Board, Municipal Manpower Commission, and several committees of the National Research Council, United States Department of Defense and United States Chamber of Commerce. A member of President's Science Advisory Committee when it was made part of the White House office, he was co-author of its reports on "Strengthening American Science," on scientific and technical information, on the Seabury Panel Report, and of others. He remains as consultant to this committee. He is a trustee of the Rockefeller Institute, Mellon Institute, and Aerospace Corporation.

This will be the fifty-seventh presentation of the Perkin Medal, an award which commemorates the work of Sir William Henry Perkin, the chemist who synthesized mauve dye and laid the ground-work for the coal chemicals industry, which has evolved into modern synthetic chemistry.

F. R. Kappel Receives 1962 Silver Quill Award

F. R. Kappel, A.T.&T. Board Chairman, is the 1962 recipient of the Silver Quill Award, an award presented annually by the National Business Publications to an American who has distinguished himself by his dedicated service to business, industry and government. The award was presented on February 7 by Vice President Lyndon B. Johnson. Past recipients of the award have included: Vice President Johnson; Arleigh A. Burke, Admiral U.S.N., retired; James H. Doolittle, Lt. General U.S.A.F., retired; former President Herbert Hoover; former Vice President Richard Nixon; and Sam Rayburn and Joseph W. Martin, Jr. both former speakers of the House of Representatives.

In accepting the award, Mr. Kappel said that "this year's award really honors many people and not just me. I have been in the Bell System nearly 39 years. It doesn't take that long to realize that whatever credit we earn is the work of able and devoted men and women all through the business. And it doesn't lessen my personal appreciation, it only increases it, to be able to say on their behalf as well as for myself—thank you for this recognition."

The theme of the dinner was the challenge of universal communications, and in his remarks Mr. Kappel touched on the question of how business could better communicate its ideas and purposes.

B. T. Matthias To Receive Research Corporation Award

Dr. Bernd T. Matthias has been named recipient of the 27th Research Corporation Award. Dr. Matthias is currently serving both as a member of the Physical Research Laboratory of Bell Laboratories and as professor of physics at the University of California at La Jolla.

The Research Corporation Award, which was given first in 1925, will be presented to Dr. Matthias in New York City, following a dinner in his honor on April 18. The award consists of a plaque and a citation noting Dr. Matthias' outstanding contributions in the fields of superconductivity and ferroelectricity and an honorarium of $10,000. About one hundred leading scientists, educators and businessmen, and their wives, are being invited to join the Directors of the foundation in honoring Dr. Matthias at the dinner. The citation states "For his discovery of new and unexpected ferroelectrics and superconductors including those with the highest superconducting transition temperatures and those which have recently been shown to have the greatest potential for the production of large magnetic fields on a scale heretofore considered impossible. His far-reaching researches have given insight and stimulus to man's understanding of the material world and are destined to have widespread scientific and technological applications." The bulk of the research cited was carried out at Bell Laboratories.

Given at irregular intervals before World War II, the Research Corporation Award has been made annually since 1946. The award is intended to recognize outstanding scientific achievements not previously accorded major recognition. Eight of those who have received this Award since World War II have subsequently re-

ceived Nobel prizes for the research work cited in their Research Corporation Awards. Previous recipients of the award from Bell Laboratories have been H. S. Black and C. E. Shannon.

Established in 1912, Research Corporation is one of the oldest foundations in the United States. For most of its first fifty years of existence it was concerned primarily with the support and advancement of specific scientific research undertakings in the colleges and universities of this country. With the vast increase in federal funds available for research in recent years, the foundation has concerned itself increasingly with a program for the strengthening of the sciences at the liberal arts colleges and smaller universities.

Dr. Matthias is a naturalized U. S. citizen, born in Frankfurt, Germany. He received his Ph.D. in Physics at the Federal Institute of Technology, Zurich, Switzerland, in 1943, where he carried on research until 1947. He spent a year at MIT before becoming a member of the technical staff of Bell Laboratories in 1948. He spent two years on leave from the Bell Laboratories as assistant professor of physics at the University of Chicago from 1949 to 1951, and then returned to Bell Laboratories. He is a fellow of the American Physical Society.

W. G. Pfann Given Gano Dunn Medal

William G. Pfann, Metallurgical Research Laboratory, has been named the 1963 recipient of the Gano Dunn Medal for professional achievement, presented annually to an outstanding graduate of the Cooper Union School of Engineering by the Cooper Union Alumni Association. The medal is named for the New York engineer and former chairman of the Cooper Union trustees, Gano

Dunn, who died in 1953.

Mr. Pfann, head of the Department of Crystal Growth and Zone Melting, also received a citation from Cooper Union in 1956. He has been associated with Bell Laboratories since 1935. During World War II he did significant work in developing silicon "cat's whisker" crystal detectors for use in radar receivers. After the war he devised a method for eliminating a certain type of electrical contact erosion. Since 1948 he has been particularly active in exploring semiconductor processes and devices related to the transistor. During this period he invented the zone melting process, an extremely simple method of refining germanium and other materials to practically perfect purity.

He holds 45 patents on zone melting, semiconductor devices, and crystal growth techniques, with about 15 more pending. For his work in zone melting he has received a number of medals and awards from domestic and foreign professional groups.

Mr. Pfann recently returned to the Laboratories from the University of Cambridge, England, where he was a visiting scientist at the Department of Metallurgy and an overseas fellow of Churchill College.

Transistorized Submarine Cable Planned For 1966 Use

During his appearance as a witness before the Senate Commerce Subcommittee on Communications in Washington on February 18, A.T.&T. Executive Vice President James E. Dingman told of a new overseas transistorized submarine cable, expected to be available for use in 1966. Mr. Dingman said that work has been underway since 1954 to perfect the transistorized undersea cable, and that development of the cable began early in 1962. He

explained that the new cable will carry 720 voice circuits or one television channel.

The A.T.&T. Vice President was one of several witnesses called before the Subcommittee to report on the present status of communications satellites and to explain satellite communications programs planned for the future.

Appearing with Mr. Dingman was Eugene F. O'Neill, Director of the Satellite Communications Laboratory at Bell Laboratories, who told subcommittee members of the operations of Telstar, its failure, and successful reactivation.

Undersea Cable to Jamaica Completed

The laying of a new underseas cable from Florida to Jamaica, British West Indies, has been completed by the cableship *Alert*. The Long Lines Department of A.T.&T. has announced that telephone service over the 850-mile cable will be established shortly.

This latest cable system uses a single armorless-type cable, a substantial portion of which was made at the Baltimore Works of the Western Electric Company. It employs repeaters developed by Bell Laboratories and made at the Clark Shops of the Kearny Works. The terminal carrier equipment was made at the Merrimack Valley Works of Western Electric. The new $14-million system has the capacity of 128 simultaneous calls—more than any other ocean cable in use today.

The cable will serve as the main artery of an "all cable" network planned for Central and South American points. Extension from Jamaica to the Canal Zone is scheduled for early spring.

Telephone service between the United States and Jamaica was first begun in 1936 over a single radio-telephone circuit. Today, there are 11 telephone circuits handling about 50,000 calls annually.

PATENTS

Following is a list of the inventors, titles and patent numbers of patents recently issued to members of the Laboratories.

Aaronson, D. A.—*Pulse Position Detector Utilizing the Storage Effect of pnpn Diodes* — 3,072,-804.

Abraham, L. G.—*Line Protection in Radio Relay Systems*—3,-072,748.

Alterman, M. E. and Irland, E. A. —*Telephone Line Scanning Circuit*—3,073,907.

Apgar, J. M. — *Broadband Coupling to Comb-Structure*—3,074,023.

Barney, H. L.—*Unitary Artificial Larynx*—3,072,745.

Blaha, A. L., Feiner, A., Feldman, T., and Klie, R. H.—*Switching Device*—3,075,059.

Cahill, H. D. and Dagnall, C. H., Jr.,—*Automatic Calling Number Identification*—3,071,650.

Chapin, D. M.—*Telemetering System*—3,072,894.

Clemency, W. F.—*Speakerphone* —3,075,045.

Cook, J. S.—*Noise Reduction in Parametric Amplifier* — 3,072,-861.

Dagnall, C. H., Jr.—see Cahill, H. D.

Davis, C. G.—*Dual Encoder for PCM*—3,073,904.

Feiner, A.—see Blaha, A. L.

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Goodall, W. M.—*Cipher System for Pulse Code Modulation Communication System*—3,071,-649.

Gordon, E. I.—*Electron Discharge Device*—3,072,817.

Grubelich, M. J.—*Continuity Device*—3,074,520.

Hochgraf, L. and Stone, H. A., Jr.—*Prevention of Power Harmonic Interference in Bridged Subscriber Loops*—3,073,908.

Irland, E. A. — see Alterman, M. E.

Jack, R. F., Prescott, R. E., and White, P. R.—*Printed Wiring Assemblies*—3,075,280.

James, D. B.—*Video Interchange By Digital Band and Scan Conversions*—3,073,896.

Kitsopoulos, S. C.—*Bandwidth Reduction System*—3,071,727.

Klie, R. H.—see Blaha, A. L.

Kluver, J. W.—*Cyclotron Wave Amplifier with Decreased Magnetic Bias*—3,075,154.

Kowaleski, C.—*Encoding Device* —3,075,759.

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Llewellyn, F. B.—*Pulse Code Modulation Transmission* — 3,-075,147.

Mattke, C. F. and Mosing, L. W. —*Telephone Set*—3,073,911.

McConville, J. H.—*Semiconductor Device Contact*—3,075,280.

Meacham, L. A. and Schenker, L. —*Signaling System*—3,076,059.

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Prescott, R. E.—see Jack, R. F.

Remeika, J. P.—*Growth of Single Crystals of Corundum and Gallium Oxide*—3,075,831.

Richey, J. D.—*Bearing Assembly* —3,073,654.

Runyan, J. P.—*Digital Phase Equalizer, Automatically Operative, in Accordance with Time-Inverted Impulse Response of the Transmission Circuit*—3,071,739.

Sauer, H. A. and Turner, D. R.— *Low Resistance Contact for Semiconductors*—3,071,522.

Schenker, L.—see Meacham, L. A.

Schroeder, M. R.—*Time Domain Vocoder*—3,071,652.

Schulte, H. J., Jr. — *Magnetic Comparison Circuit*—3,072,800.

Schulz-DuBois, E. O. and Tabor, W. J.—*Traveling Wave Maser* —3,076,148.

Seidel, H.—*Reciprocal Gyromagnetic Loss Device*—3,072,869.

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Dillon, J. F. and Remeika, J. P., *Visual Observation of Magnetostatic Modes*, Appl. Phys. Letters, 2, 38-9, Jan. 15, 1963.

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*Not a Laboratories' employee.

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Amster, S. J., *A Modern Look at Bayes*, IRE, New York Metropolitan Chapt., Prof. Group on Reliability and Qual. Control, New York City.

Averbach, E., *Reading Out the Buffer Stage*, Am. Assoc. Advance, Sci., Philadelphia.

Baba, P. D., Gyorgy, E. M. and Schnettler, F. J., *Two-Phase Ferrites for High-Speed Switching*, Conf. on Magnetism and Magnetic Materials, Pittsburgh.

Baker, R. G., *The Use of Electro-Plated Metals in Static Low-Voltage Contacts*, Am. Electroplaters Soc., Chicago.

Blumberg, W. E., *Electron Resonance Techniques in the Study of Proteins*, Protein Foundation, Cambridge, Mass.

Brattain, W. H., *Surface Properties of Germanium in an Aqueous Electrolyte*, General Electric Co., Richland, Wash.

Brattain, W. H., *The Germanium Aqueous Electrolyte Interface*, U. S. Naval Ordnance Lab., Silver Spring, Md.

Buchsbaum, S. J., *Wave Propagation in a Uniform Plasma*, Lockheed Magnetohydrodynamics Symp., Palo Alto, Calif.

Buchsbaum, S. J., *Radio-Frequency Emission from a Plasma in a Strong Magnetic Field*, Am. Phys. Soc., Div. Plasma Physics, Atlantic City, N. J.

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Chandross, E. A. and Trozzolo, A. M., *Molecular Complexes of Ferrocene*, Am. Chem. Soc., Metropolitan Regional Mtg., Newark, N. J.

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Darnell, P. S., *Some Reliability Considerations for Telstar*, IRE Prof. Group on Reliability and Quality Control, New York City.

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Deutsch, M., *The Face of Bargaining*, Calif. State Psych. Assoc., Los Angeles.

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